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U. S. ARMY AVIATION MATERIEL LABORATORIES
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AN EVALUATION OF THE SMOKE-WIRE TECHNIQUE FOR MEASURING VELOCITIES IN AIR

Aerophysics Research Report No. 70

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Prepared by

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ABSTRACT

In the smoke-wire technique, oil is evaporated from a very thin, high-resistance wire by the passage of a large electric current through the wire from a capacitor. The resulting line of smoke is carried downstream with the local velocity of the air, deforming so that a photograph of the smoke line after a measured time delay provides a velocity profile. Since the time delay is very short, this velocity profile is very close to the actual velocity profile at the location of the wire. The technique was evaluated in two- and three-dimensional air flows, both laminar and turbulent, by comparisons with theoretical profiles. Experimental velocity profiles compared quite favorably with theoretical solutions for several different types of flows, including boundary layers, jets, wakes, and vortices. Modifications of the technique and associated apparatus were made in order to extend its scope of application.

CONTENTS

ILLUSTRATIONS

2. THE OIL-COATED WIRE TECHNIQUE

In the "smoke-wire" method, oil is evaporated from a very thin, high-resistance wire by the passage of a large electric current through the wire from a capacitor discharge. This forms a thin line of smoke at the wire. The line of smoke is carried downstream with the local velocity of the air at each point along the line and is thus deformed into the shape of the velocity profile. At the discharge of the capacitor a time-delay circuit is actuated which, after a predetermined time delay, simultaneously fires a strobe light and camera to illuminate and photograph the smoke. The displacement of the smoke can be measured from the film, and by using the known time delay, velocity profiles can be obtained.

In 1964, Cornell (reference 2) evaluated several different liquids for coating the wire. He concluded that the most suitable substance was a commercial "model train smoke" manufactured by Life-Like Products, Inc., of Baltimore, Maryland. Therefore, this type of oil was used in this evaluation of the technique.

A. EXPERIMENTAL METHOD

The present experiments were made using a nichrome wire 0.0015 inch in diameter. In all experiments, except the one involving the confined vortex, the wire was approximately 2 inches long; in the vortex experiment, a 6-inch wire was used. The wire in all but the vortex experiment was mounted on a support of beryllium copper strips, 0.025 inch thick and 0.2 inch wide (Figure 1), which maintained a slight tension in the wire and served as electrical conductors. The support was given a streamline cross section in the flow direction in order to minimize disturbances.

In the course of this evaluation, two strobe-delay circuit units were used, one mounted permanently in an open-circuit wind tunnel (Figure 2) and the other, a portable unit (Figure 3). Both units employ an 80 watt-second strobe light. The time-delay circuit diagram is shown in Figure 4. Two 35-millimeter cameras were used, a Practina FX and an Exacta VX2A, both with 50-millimeter lens and set at f2. Tri-X Estar base film was used throughout.

B. DATA REDUCTION

Velocity measurements were made from the photographs of the smoke profiles in the following manner: The 35-millimeter negatives were enlarged in a microfilm viewer, and the smoke profiles were carefully traced onto small-grid graph paper. The displacement of the smoke line from the wire was then measured at a number of points along the line

and scaled to actual size. Finally, division of these displacements by the time delay yielded the velocities at the corresponding points at the position of the wire.

C. OIL APPLICATION METHODS

Oil had previously been applied to the wire with a small art brush. This produced good results, but it proved unfavorably time-consuming, as well as inconvenient, and in some circumstances, impossible.

A remote-controlled application was attempted using a hypodermic syringe as the applicator, but this proved unsuccessful. In this method, drops of oil were introduced onto the top of the wire from the syringe. However, in flowing air with appreciable velocity, the air current removed the oil drops before the wire became sufficiently coated.

An aerosol method of coating the wire was then tested. First, a commercial aerosol hair spray was used to determine if the wire could be sufficiently coated by aerosol application in moving air. It was discovered that directing the aerosol mist slightly upstream of the wire gave excellent results and produced very good smoke. However, after firing the wire several times, a residue collected on it forming heat insulation which made the velocity profiles too dim to interpret.

The most satisfactory results were obtained by applying the model train smoke with a paint spray gun (Figure 3). This method reduced the experimentation time by a factor of 6, as compared to the brush application. Spray application also has the important advantage of allowing application in regions impossible to reach with a brush.

The only disadvantage in spraying the wire was found to be pollution of the air when experimenting outside the tunnel in a confined room. In a tunnel with moving air, however, the excess mist is carried out the exhaust, and pollution poses no problem.

3. EVALUATION IN LAMINAR TWO-DIMENSIONAL FLOWS

A. BOUNDARY LAYER ON A FLAT PLATE

The wire, attached to its supports, was mounted on the surface of a thin, flat plate (Figure 5), which was mounted in an open-circuit wind tunnel, parallel to the flow. The plate was of 12-inch chord and 23¼-inch span and was 1/8 inch thick with a rounded leading edge. The wind-tunnel test section was octagonal, 23¼ inches in width, 24 inches in height, and 46½ inches long. The wire support was aligned perpendicular to the tunnel axis. Particular care was taken to align the wire exactly perpendicular to the plate, since the wire is the reference line from which displacements of the smoke are measured.

The strobe light was mounted directly above the plate at a distance of about 1 foot with its axis perpendicular to the plate. Both the strobe assembly and the delay circuit are permanent fixtures of this wind tunnel. The camera was mounted outside the tunnel with its axis perpendicular to the wire and to the tunnel axis. The camera was located about 2 feet from the tunnel, directly aligned with and focussed on the center of the wire. Measurements were taken with the probe located 2 inches and 8 inches from the leading edge of the plate, at the mid-span position. Time delays of 2.0, 4.0, and 6.0 milliseconds were used at each location. The velocity of the air was 3 feet per second.

Figure 6 shows typical smoke profiles of the boundary layer on a flat plate. The wire was approximately 2 inches long, and the smoke displacement was about 0.5 inch at its maximum. Note that there is no distortion of the profile at the plate surface, indicating that any disturbance caused by the lower probe support is negligible. It can be seen that the boundary layer is thicker at 8 inches from the leading edge, as it should be.

Experimental velocity profiles taken from several such photographs are compared with the Blasius solution (reference 6) for laminar flow over a flat plate in Figure 7. There is better agreement and less scatter at 8 inches from the leading edge, since the influence of irregularities from the leading edge is less than at 2 inches. There is a lower limit, as well as an upper limit, to the time delay that can be used, since the shaded points, which correspond to the shortest delay, are not at all in agreement with the theoretical curve. The other three time delays yielded very good agreement with the theoretical curve, even at the surface of the plate.

The upper limit on the time delay that can be used is a result of the fact that the velocity is not constant in the direction of flow. Only in the rare case of constant velocity in this direction is the velocity which is measured the true velocity at the position of the

wire. However, the error from this source decreases as the time delay decreases. The lower limit on the time delay is due to the finite time required for evaporation of the oil from the wire. Too short a time delay results in error, since the time between current discharge and formation of the smoke line may then be large compared with the time during which the smoke is transported downstream.

B. MEASUREMENTS IN THE WAKE OF A FLAT PLATE

Figures 8 and 9 show the smoke-wire arrangement used for taking velocity measurements in the wake of a flat plate. The same plate, tunnel arrangement, and strobe-delay circuit used for the flat-plate boundary layer were used for the wake investigation. The probe was mounted on a ring stand and carefully oriented so that the wire was perpendicular to the plane of the plate. The wire support was aligned perpendicular to the tunnel axis. The strobe light was directly above the wire with its axis perpendicular to the plane of the plate. The camera was aligned with the wire in the same manner as described in Part A. Measurements were taken with the probe located at 1.30 and 3.08 inches behind the trailing edge of the plate, at mid-span, with the center of the wire in the plane of the plate. Time delays of 5.0, 10.0, and 15.0 milliseconds were used. The tunnel airspeed was 3 feet per second.

Two smoke profiles of the flat plate wake are shown in Figure 10. The actual size of the wire in these photographs was approximately 2 inches, and the smoke displacement was about 0.5 inch at its maximum. The small oscillation perpendicular to the plane of the plate that is expected in the wake of a flat plate, because of Tollmien-Schlichting waves, can be seen by observing these photographs in sequence. There is particularly good symmetry here, and there is no abrupt change of slope at the center line.

Figure 11 is a comparison of experimental data with the laminar flat plate wake solution of Goldstein (reference 6). There is better agreement at 3.08 inches from the trailing edge than there is nearer the trailing edge because the plate had a finite thickness. Again, the short delay, represented by the dark points, produced erroneous data. The scatter, which is symmetric about the theoretical curve, is due to the above-mentioned slow fluctuation of the wake perpendicular to the plane of the plate.

4. EVALUATION IN TURBULENT FLOWS

In turbulent flow the photograph records a profile of the instantaneous velocity, provided the delay time is much shorter than the period of turbulent fluctuation. Therefore, time-average or mean velocity can be obtained by averaging the measurements taken from a large number of photographs taken under the same conditions. Subtracting this mean velocity profile from each instantaneous profile yields the instantaneous turbulent fluctuation in the flow direction. The magnitude of this fluctuation can then be averaged to determine the root-mean-square of the turbulent fluctuation.

A. TURBULENT BOUNDARY LAYER ON A FLAT PLATE

Cornish (reference 3) measured the velocity in the turbulent boundary layer on a flat plate in his preliminary evaluation of the smoke-wire technique. The fluctuating nature of the velocity can be clearly seen in his photographs, some of which are shown in Figure 12. Figure 13 shows the excellent agreement of theoretical mean velocity profiles with Cornish's data, obtained by averaging over 36 profiles.

B. VELOCITY MEASUREMENTS IN A TURBULENT JET

Measurements were taken at two locations, 3.0 and 6.0 inches from the exit in a turbulent jet. The probe was mounted on a ring stand and oriented with the wire perpendicular to and intersecting the axis of the jet (Figure 14). The wire support was oriented perpendicular to the jet axis. The portable strobe-delay circuit unit was used, with the strobe light mounted directly above the wire, at a distance of about 3 feet, and perpendicular to the jet axis. The camera was located about 2 feet from the wire, oriented with its axis perpendicular to the wire and to the axis of the jet, and aligned with and focussed on the center of the wire.

The jet used had a 1.0-inch-diameter exit and was the same as that used by Faris (reference 4) in his investigations of the velocity profiles in the turbulent jet. This jet had been carefully designed to assure constant laminar flow at the exit. The flow in the jet was turbulent outside the laminar core. The speed of the jet at the exit was 40 feet per second. This experiment was conducted in a darkened room. A total of 36 photographs, typical ones of which are shown in Figure 15, were taken at each location. The wire was again about 2 inches long, and the maximum smoke displacement was about 0.15 inch.

Mean velocity profiles and root-mean-square velocity fluctuation profiles were obtained by averaging 36 photographs as discussed above. The laminar core of the jet is evident in the profiles obtained at

3.0 inches from the exit, and the fluctuating nature of the turbulent region is obvious at both locations. It was necessary to use a very short time delay (1.25 milliseconds), since the time delay must be much less than the period of the turbulent fluctuation. Otherwise, the profile will be distorted by turbulent eddies downstream of the wire.

The curve in Figure 16a is a representation of the experimental data taken 3.0 inches from the exit of the jet. The laminar core of the jet was still in existence at this location, and no adequate theory was available for comparison. The extent of the laminar core is well indicated by the flat region of the curve near the center line of the jet.

Figure 16b is a comparison of the experimental data taken at 6.0 inches from the jet exit with Faris' theoretical solution (reference 4). This location was beyond the laminar core, and the agreement with theory is very good.

Figure 17 shows the root-mean-square of velocity fluctuation at each location. The extent of the laminar core is clearly evident on both curves and is much smaller at 6.0 inches from the exit, as would be expected. The maximum value of the velocity fluctuation occurs between the laminar core and the jet boundary, since the flow was laminar at the jet boundary also.

5. EVALUATION IN THREE-DIMENSIONAL FLOWS

A. THE LAMINAR BOUNDARY LAYER ON A ROTATING DISK

Two components of the velocity can be measured with the smoke wire by using two cameras aligned at 90 degrees to each other and both perpendicular to the wire. In order to evaluate this technique for three-dimensional flow, the wire was mounted perpendicular to a 1.0-foot-diameter rotating disk, with the lower support just touching the disk. Particular attention was taken to assure that the lower support just barely touched the disk, since too much pressure between the disk and the wire resulted in frictional heating and led to the breaking of the wire.

One camera was mounted facing in the radial direction and another facing in the tangential direction, each being carefully aligned with its axis perpendicular to the wire (this arrangement is shown in Figures 18 and 19). Thus, one camera recorded the projection of the velocity in the tangential direction, and the other camera recorded the projection in the radial direction. Both cameras were located about 1½ feet from the wire, aligned with and focussed on the center of the wire. The strobe light of the portable strobe-delay circuit unit was mounted about 3 feet directly above the wire, with its axis perpendicular to the disk. Measurements were taken at two radii, 3.0 and 5.0 inches. The time delay was set at 20.0 milliseconds at both locations. The disk was rotated at 250 r.p.m. This experiment was conducted in a darkened room.

Smoke profiles in both the radial and tangential directions are shown in Figures 20 and 21. Again, the profiles are smooth all the way down to the surface of the disk. The radial velocity maximum is clearly indicated, and the profile is quite smooth around this maximum.

No theory on the laminar boundary layer on a finite disk was available for comparison with experimental results. Figures 22 and 23 show plots of the experimental data for both the radial and tangential components of velocity. All radial smoke profiles coincided almost exactly, so that only one set of data is shown in Figure 22. However, there was some scatter in the tangential profiles, and data points were taken from several different photographs in obtaining Figure 23. Because of the difficulty in measuring the rapidly increasing tangential velocities near the surface, the scatter is pronounced in this region. At a small distance from the surface, the profiles begin to coincide, and the scatter becomes very small.

B. VELOCITY MEASUREMENTS IN A CONFINED VORTEX

For this phase of the experiment the smoke wire was stretched across a Plexiglas* tube of approximately 6-inch diameter (Figures 24, 25,

* Reg. T. M., Rohn & Haas Company

and 26), perpendicular to the tube axis. The wire was located 12½ inches from the entrance end of the tube. Each end of the wire was clamped to the side of the tube and connected to the portable delay circuit. The flow entered the tube tangentially at one end and exited through a 1.0-inch hole in a plate over the cross section 26½ inches from the entrance. Again, the portable unit was used with the strobe light located about 4 feet from the wire, with its axis at about an angle of 45 degrees with the tube axis.

The velocity profiles were photographed through a glass plate over the entrance end of the tube by a camera with its axis aligned on the tube axis (Figure 24), about 16 inches from the wire. In addition to this camera, another camera was mounted about 3 feet directly above the wire with its axis perpendicular to the wire to photograph the axial profile. However, photographs of the axial component were unobtainable because of light reflection from the Plexiglas. Measurements of the tangential velocity were made by tracing the profiles onto polar graph paper and measuring the displacement as an arc length. This experiment was also conducted in a darkened room.

Since the maximum velocity in a vortex occurs very near the center, it was necessary to use very short time delays in order to keep the smoke near the center from going around several times. The shortest delay possible with the delay circuit used was 1.0 millisecond, and it was not possible to investigate vortex circulations high enough for the flow to be turbulent.

Figure 27 shows smoke profiles of the tangential velocity taken at two vortex circulations with maximum velocities of 14 and 45 feet per second. The experimental tangential velocity is compared with the laminar vortex solution of Oseen (reference 6). The lower speed was obtained with the blower near the lower limit of operation, resulting in considerable irregularity in blower speed. This caused the profiles taken at different times to differ somewhat in magnitude. Therefore, only one set of data is shown in Figure 28a. The agreement is good, but there are several points far off the curve due to the irregularities introduced by the blower.

The agreement with theory is very good, however, at the higher speed, as shown in Figure 28b. The scatter near the maximum velocity is due to the difficulty of measuring large displacements at small radii. The angular displacement here was in excess of 360 degrees, so that a small error in the radius resulted in a large error in displacement and, therefore, in velocity.

6. CURRENT APPLICATIONS IN RESEARCH

Yamada (reference 8) has recently prepared a thesis on the unsteady boundary layer on an oscillating flat plate in which the smoke wire was used exclusively in obtaining data. Figure 29 shows typical smoke profiles of the boundary layer on an oscillating plate. In order to obtain smoke profiles under such conditions, it is imperative that the delay be much less than a period of oscillation.

Currently, the Aerophysics Department of Mississippi State University is investigating the boundary layer on the wing of a sailplane in flight. The smoke wire and portable apparatus are being used for obtaining data by flying at night (Figure 30).

7. CONCLUSIONS

The smoke-wire technique has been shown, by comparison with theoretical solutions, to be a useful tool for aerodynamic research, capable of measuring velocities in both two- and three-dimensional flows, laminar and turbulent. Profiles of two components of the velocity can be obtained by using only one smoke wire with two cameras. Reliable measurements without distortion can be obtained all the way down to a solid surface in the flow. Proper orientation of the wire and alignment of the camera are critical.

Measurements can be made in time-dependent flow by using a delay time much less than the period of fluctuation. Mean velocity profiles in turbulent flow can be obtained by averaging a number of instantaneous profiles. Turbulent fluctuation velocities themselves, as well as root-mean-square values, can also be measured.

Data scatter due to the technique itself is well within acceptable limits, though averaging may be necessitated by fluctuations in the flow under study, since any such fluctuation will be recorded. The technique of spraying the wire and the portable delay circuit and strobe light makes possible the use of the smoke-wire technique under practically any circumstance.

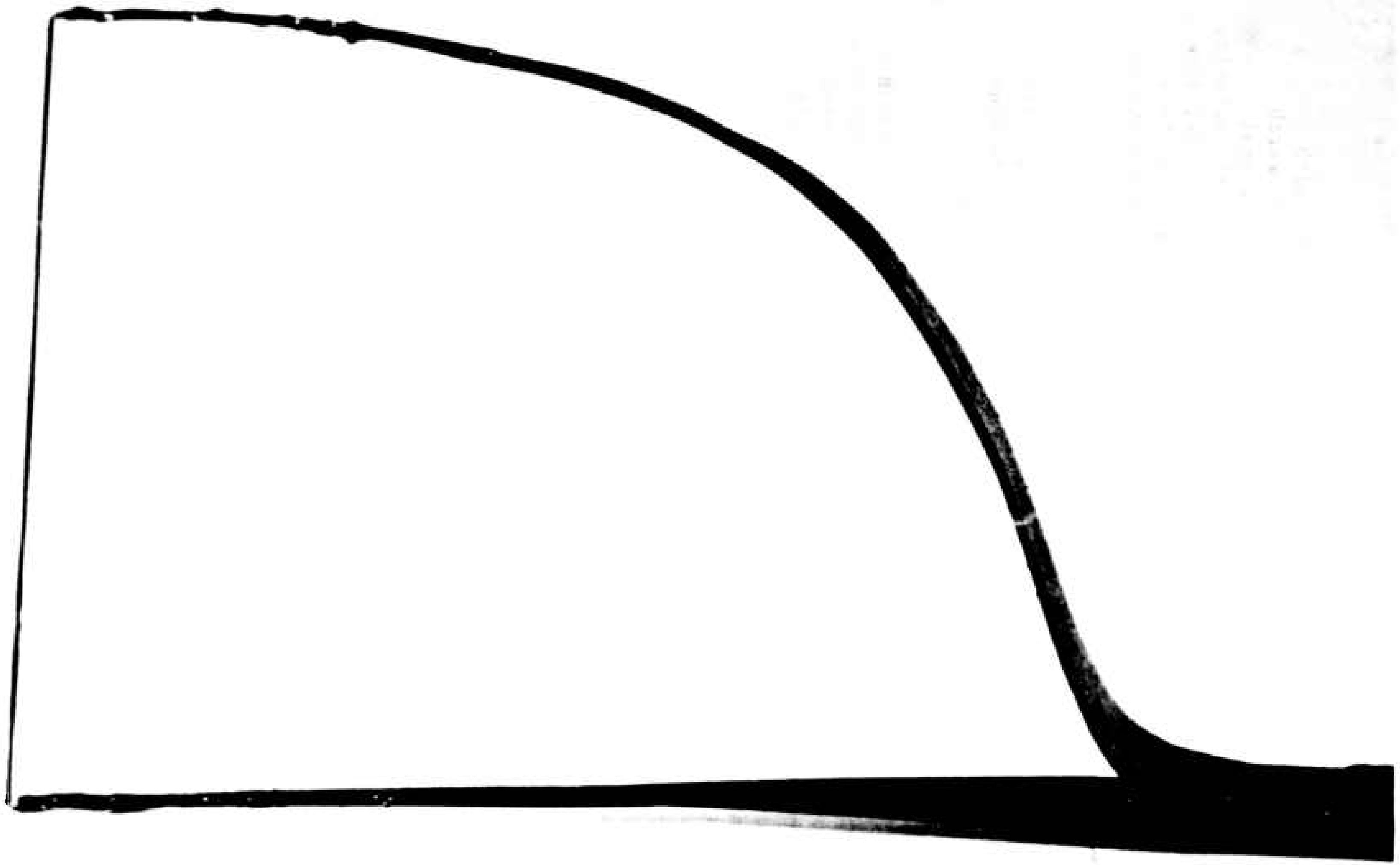


Figure 1. Smoke-Wire Probe.

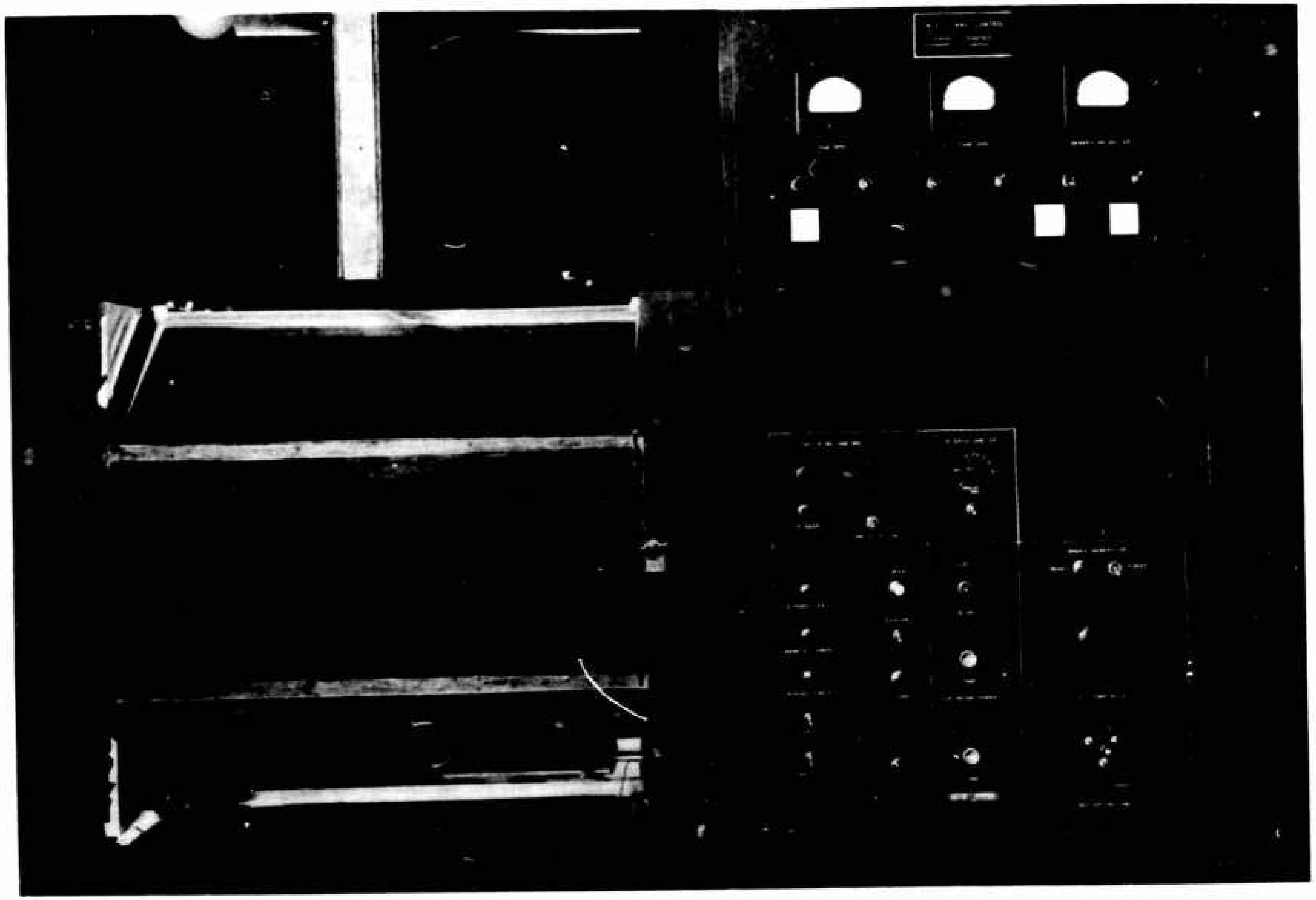


Figure 2. Permanent Strobe-Delay Circuit Control, Open-Circuit Wind Tunnel.

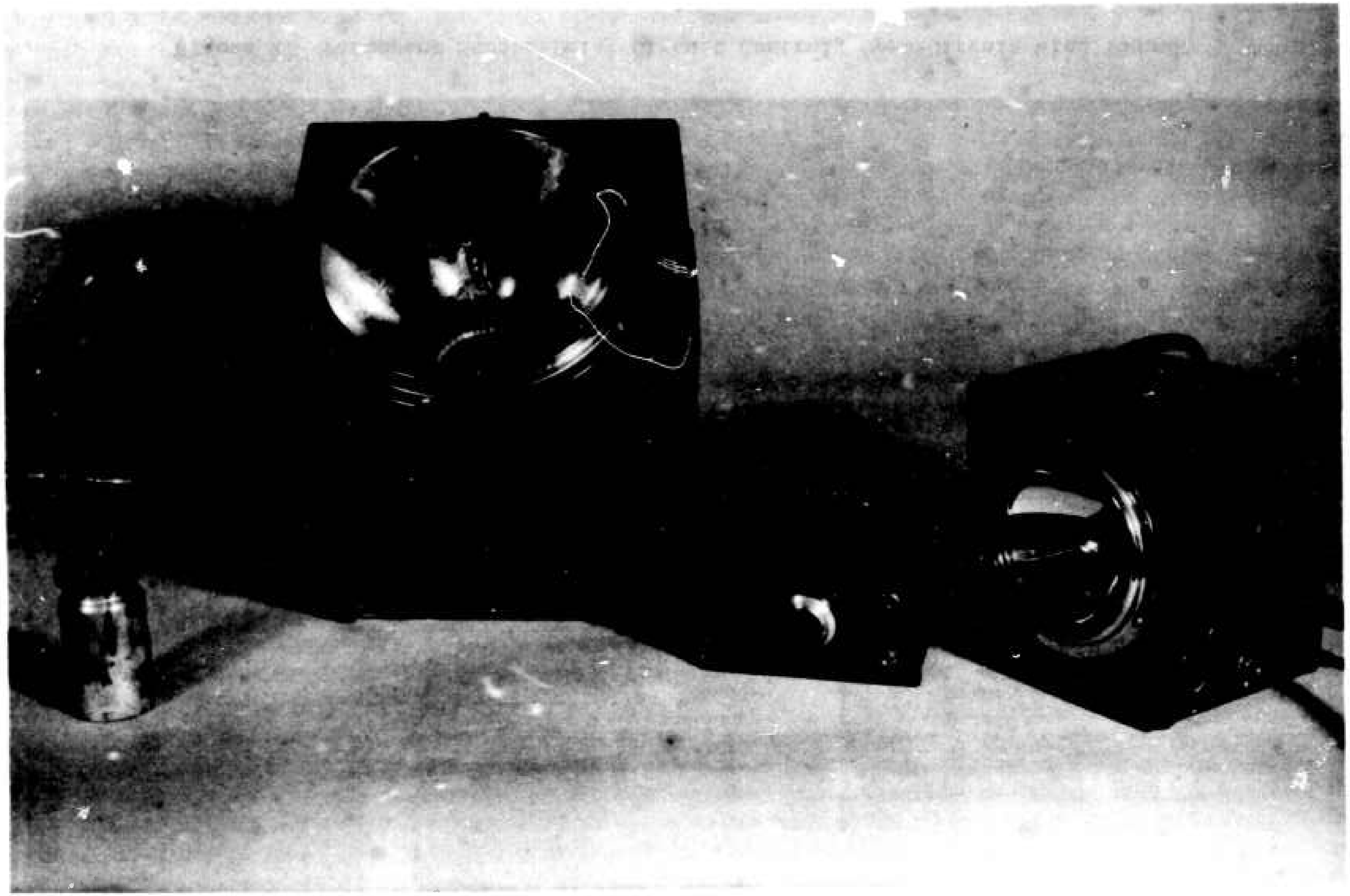


Figure 3. Portable Unit - Sprayer, Strobe Light, Delay Circuit.

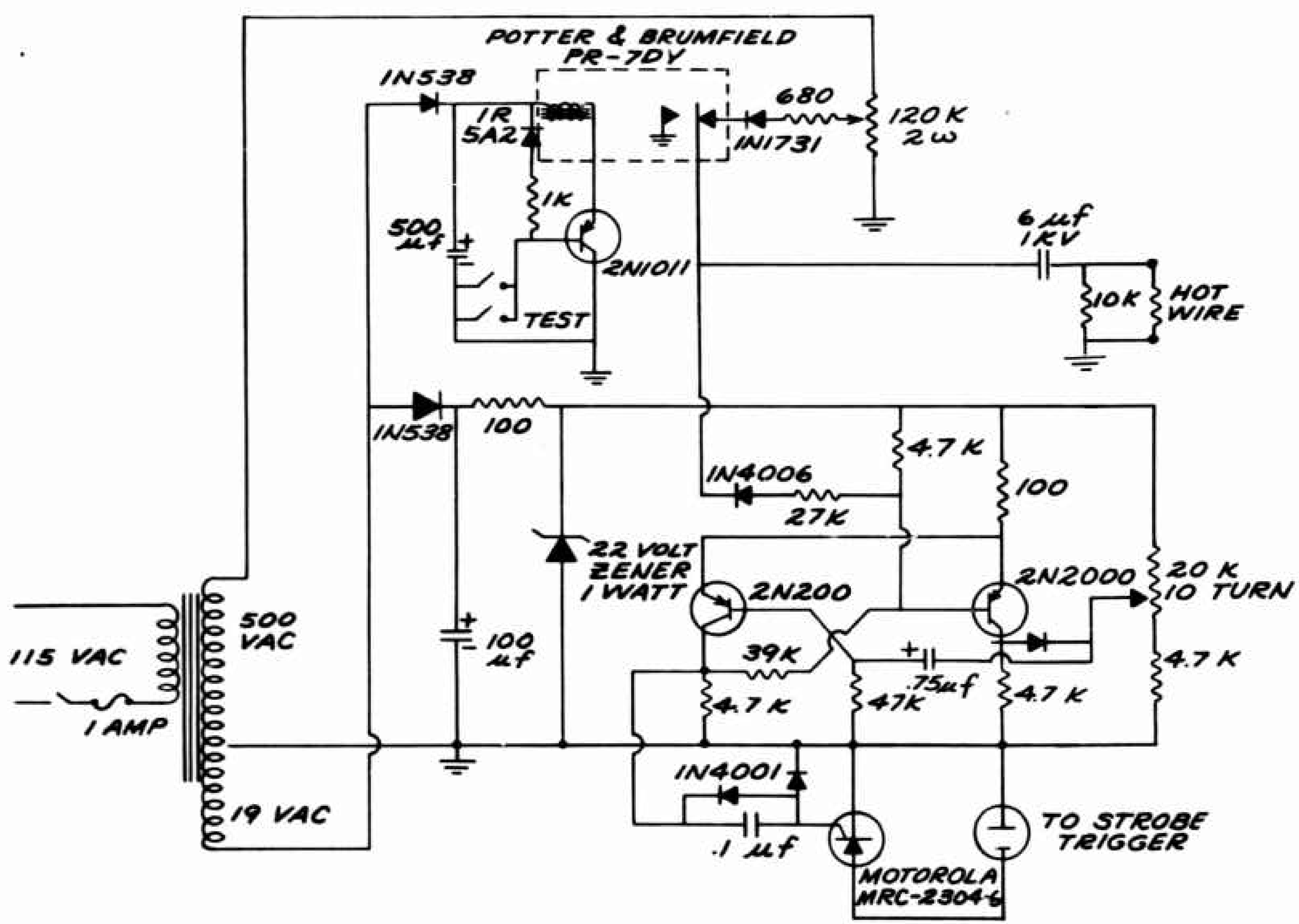


Figure 4. Delay Circuit Diagram.

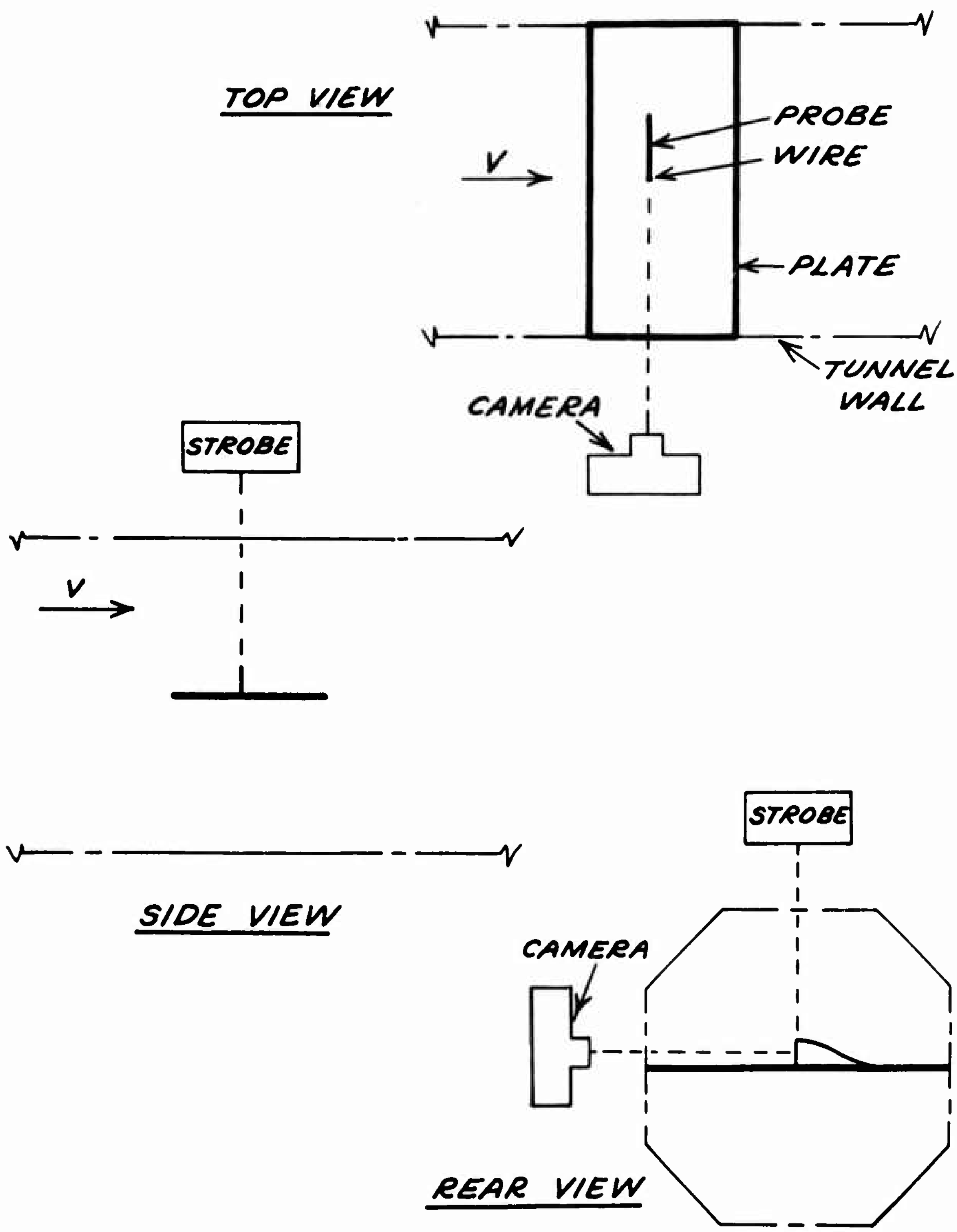
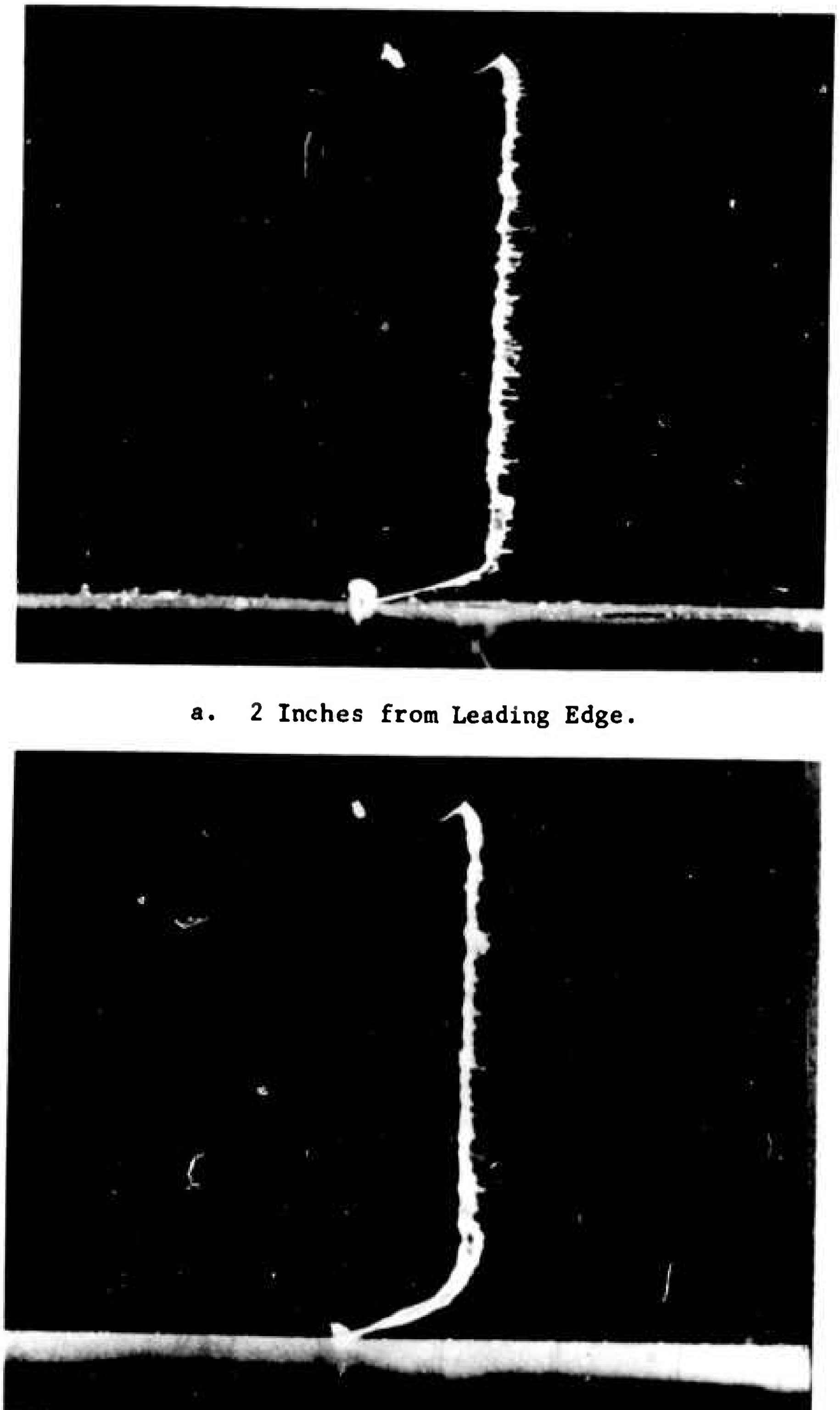


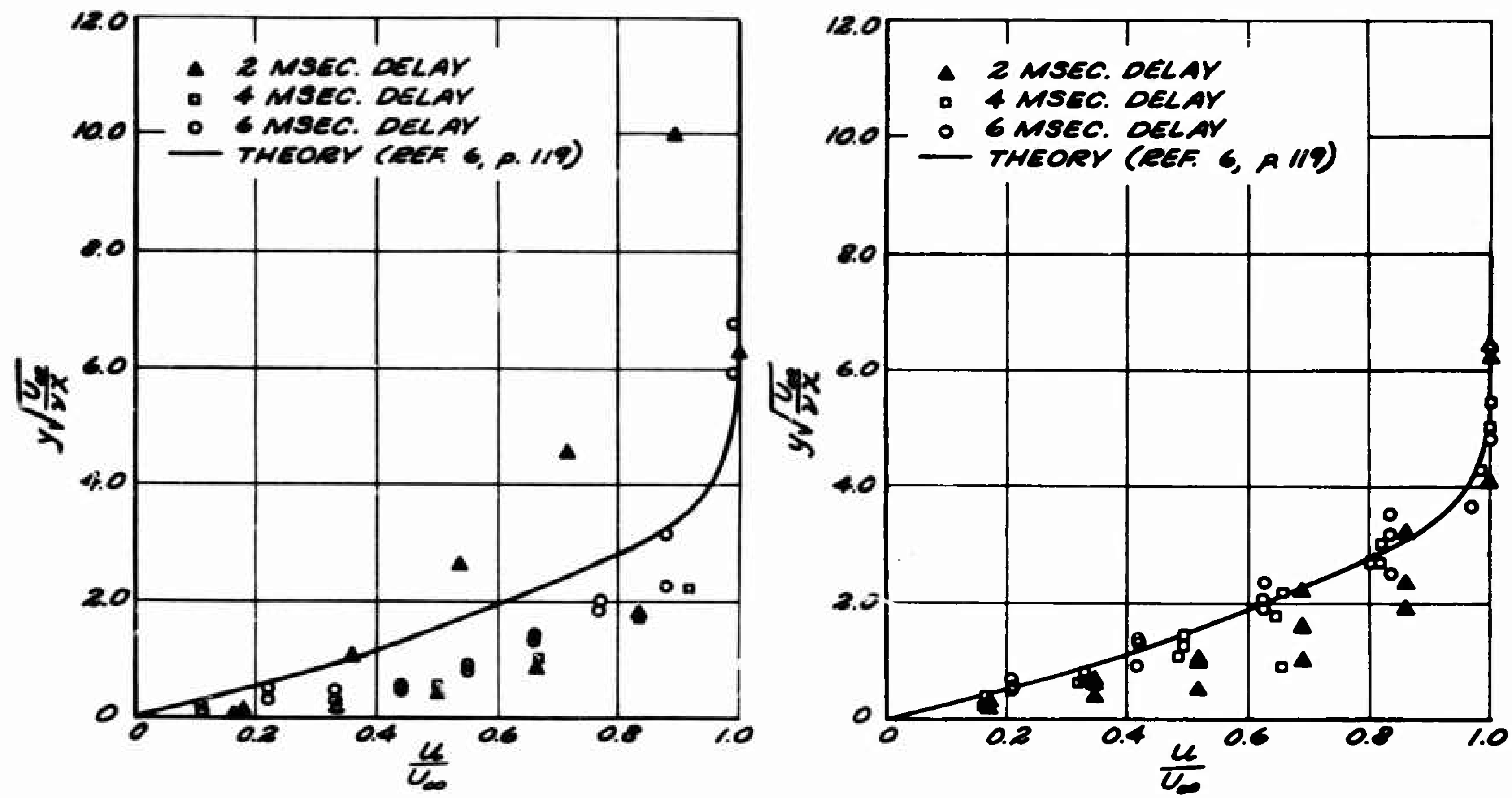
Figure 5. Apparatus Schematic for Flat Plate Boundary Layer Experiment.



a. 2 Inches from Leading Edge.

b. 8 Inches from Leading Edge.

Figure 6. Smoke Profiles of the Laminar Boundary Layer on a Flat Plate.



a. 2 Inches from Leading Edge.

b. 8 Inches from Leading Edge.

Figure 7. Comparison of Experimental and Theoretical Velocity Profiles in the Laminar Boundary Layer on a Flat Plate.

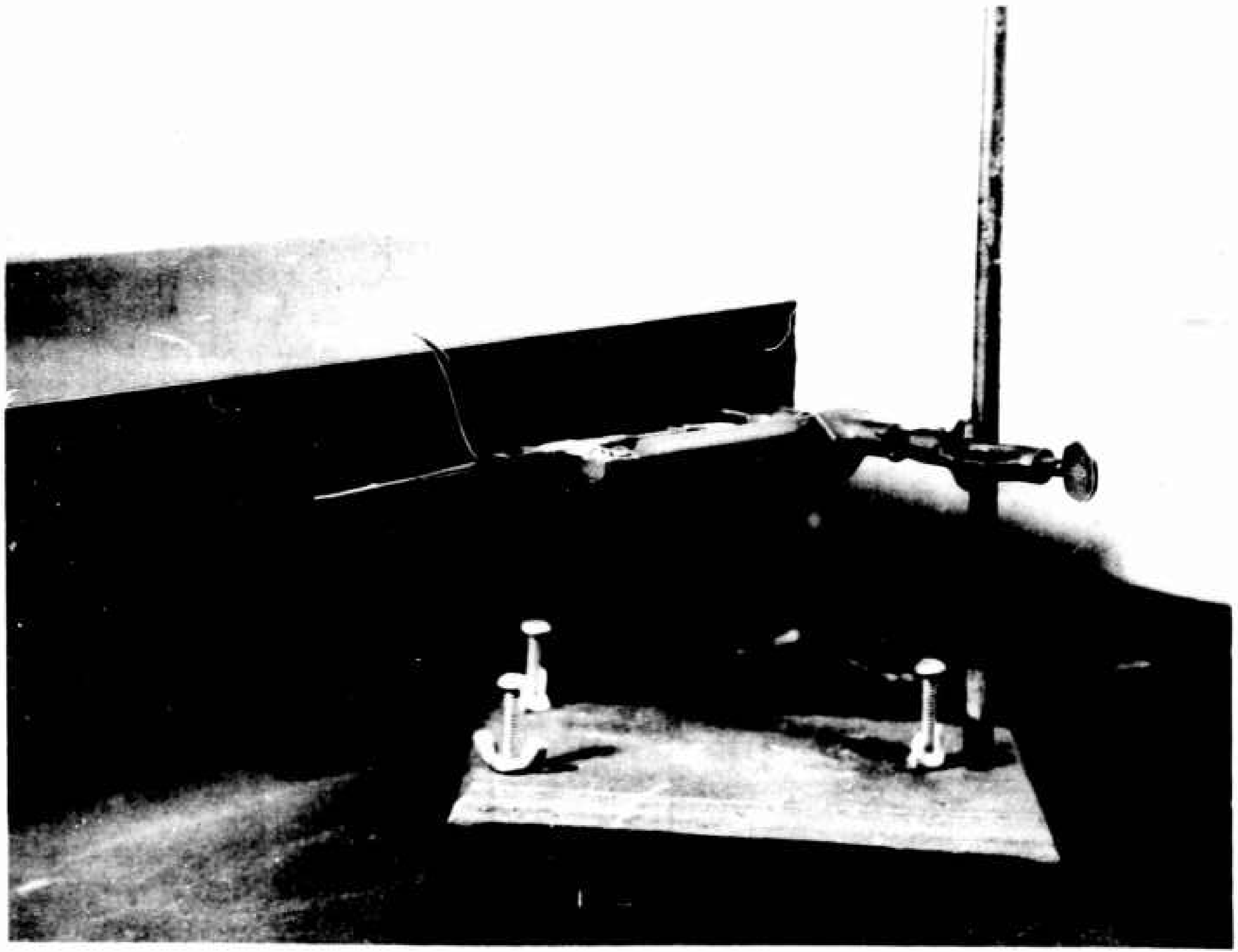


Figure 8. Probe Arrangement for Velocity Measurement in a Flat Plate Wake.

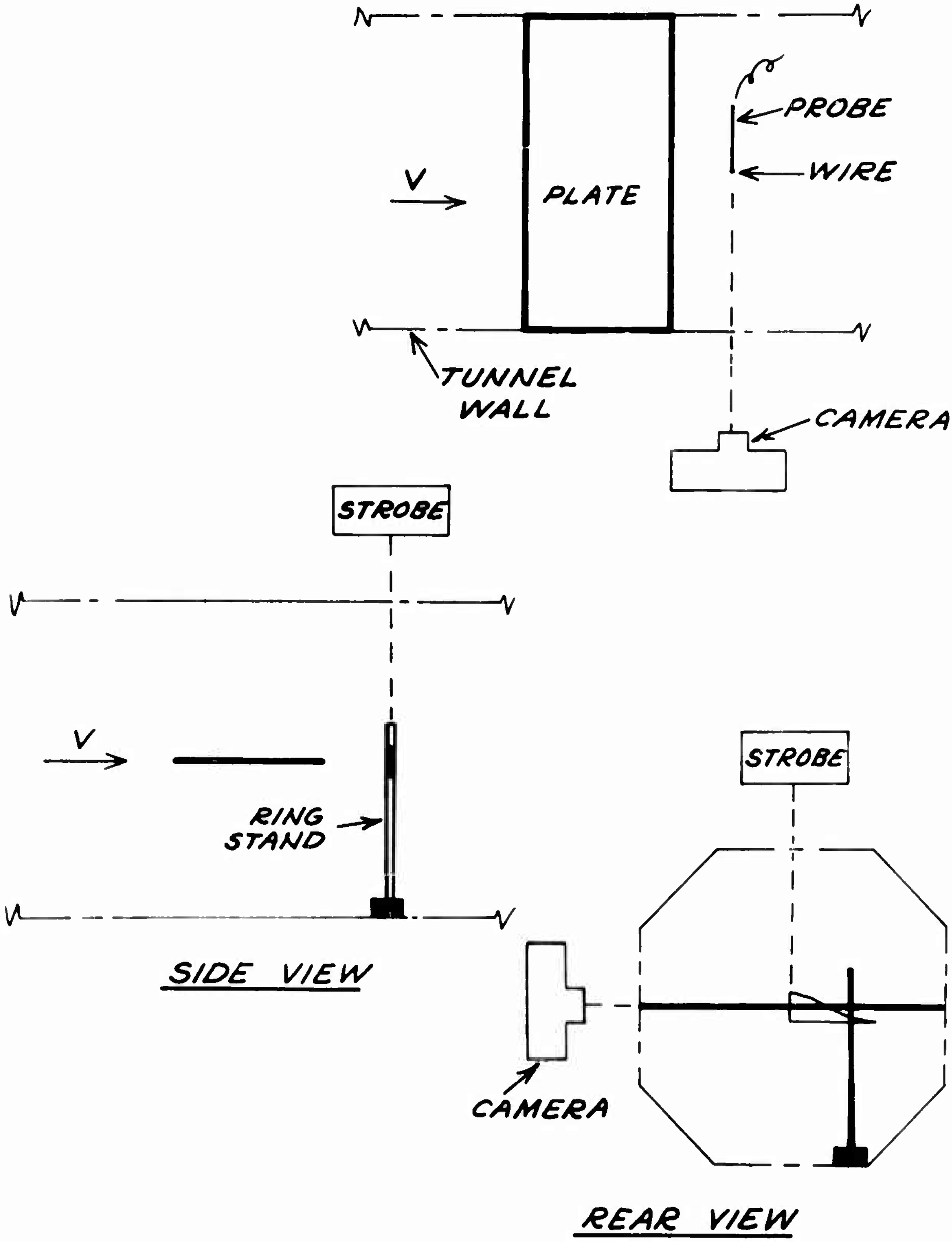
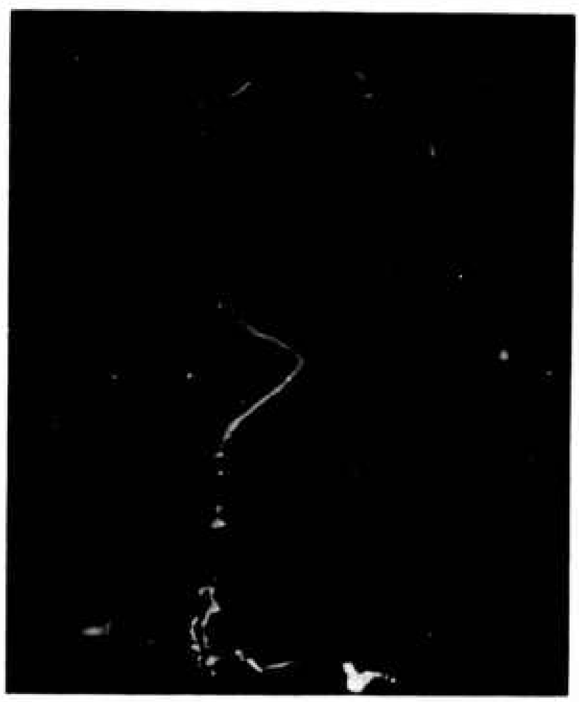


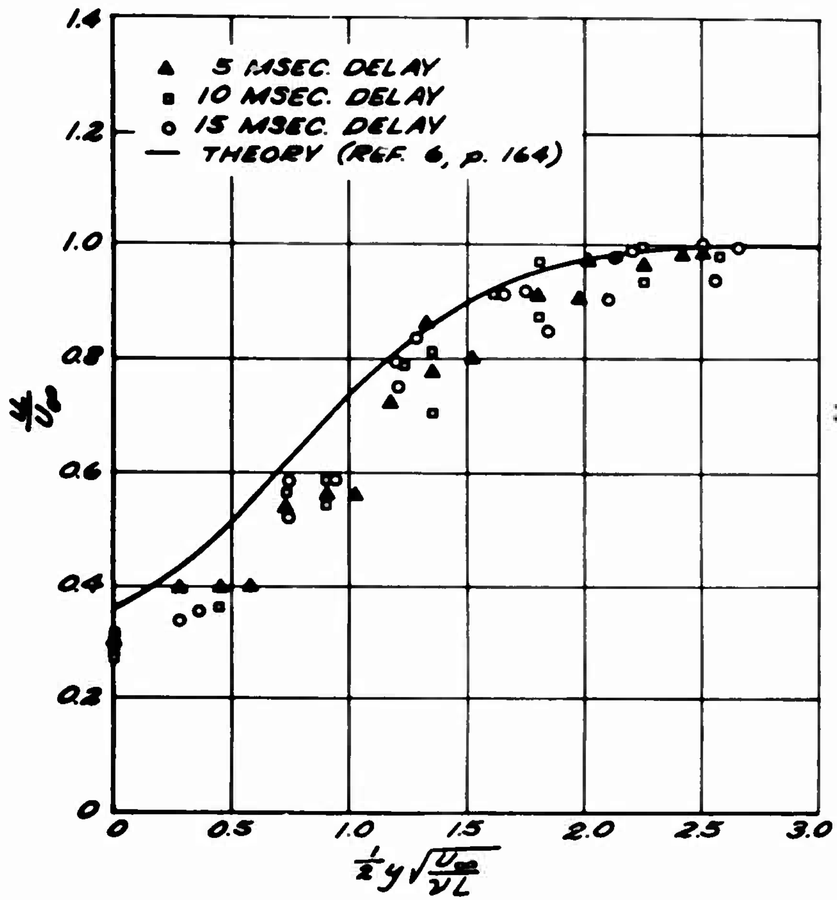
Figure 9. Apparatus Schematic for Flat Plate Wake Experiment.

a. 1.3 Inches from Trailing Edge.

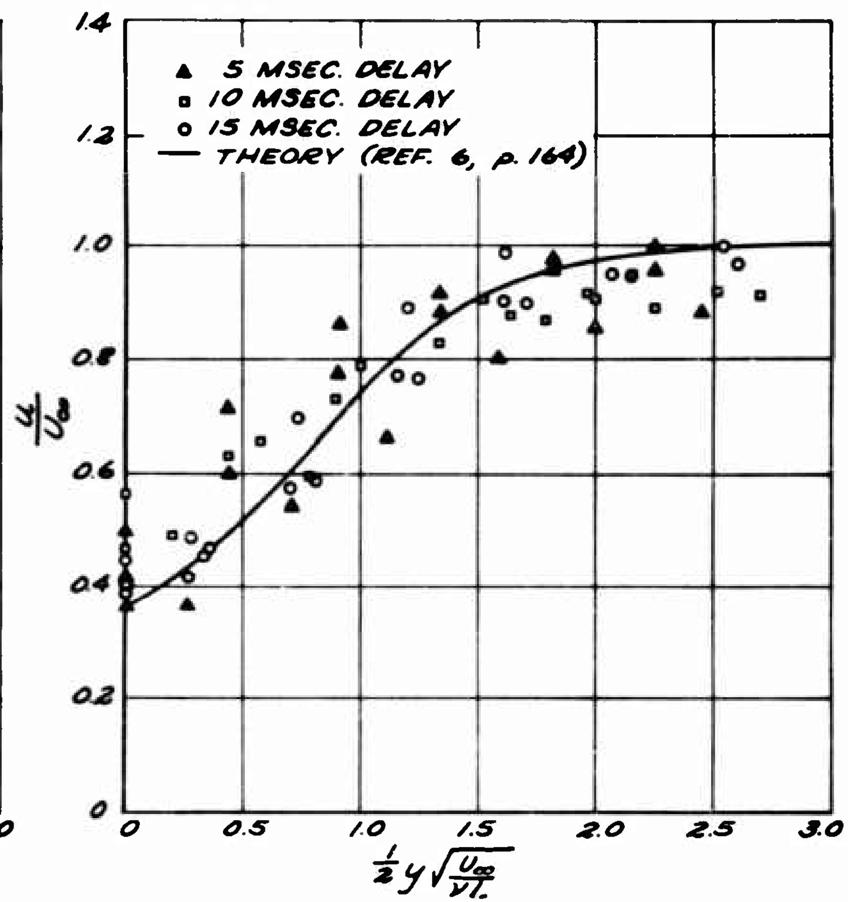


b. 3.08 Inches from Trailing Edge.

Figure 10. Smoke Profiles of the Laminar Wake of a Flat Plate.



a. 1.3 Inches from Trailing Edge.



b. 3.08 Inches from Trailing Edge.

Figure 11. Comparison of Experimental and Theoretical Velocity Profiles in the Laminar Wake of a Flat Plate.

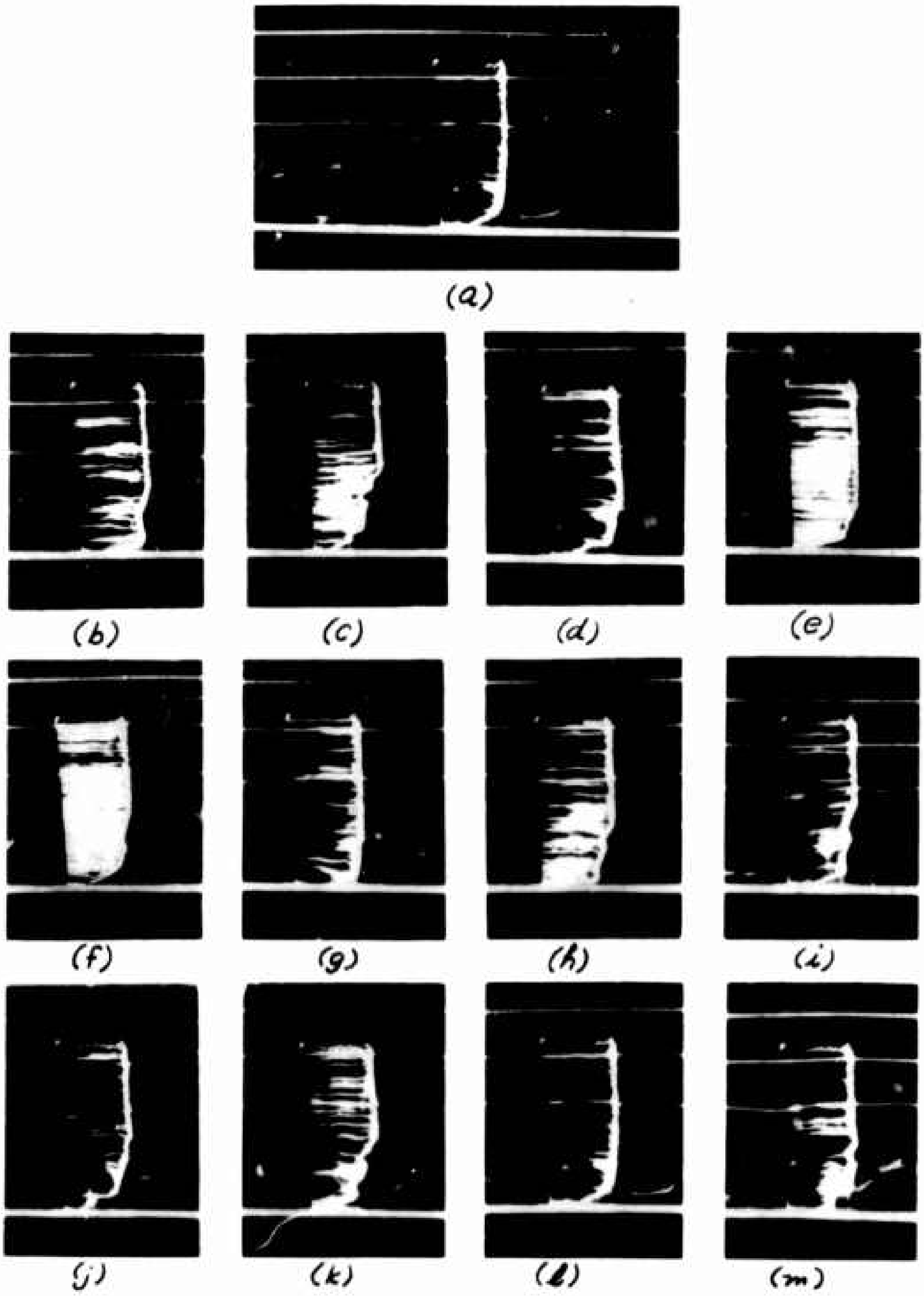


Figure 12. Smoke Profiles of the Turbulent Boundary Layer on a Flat Plate.

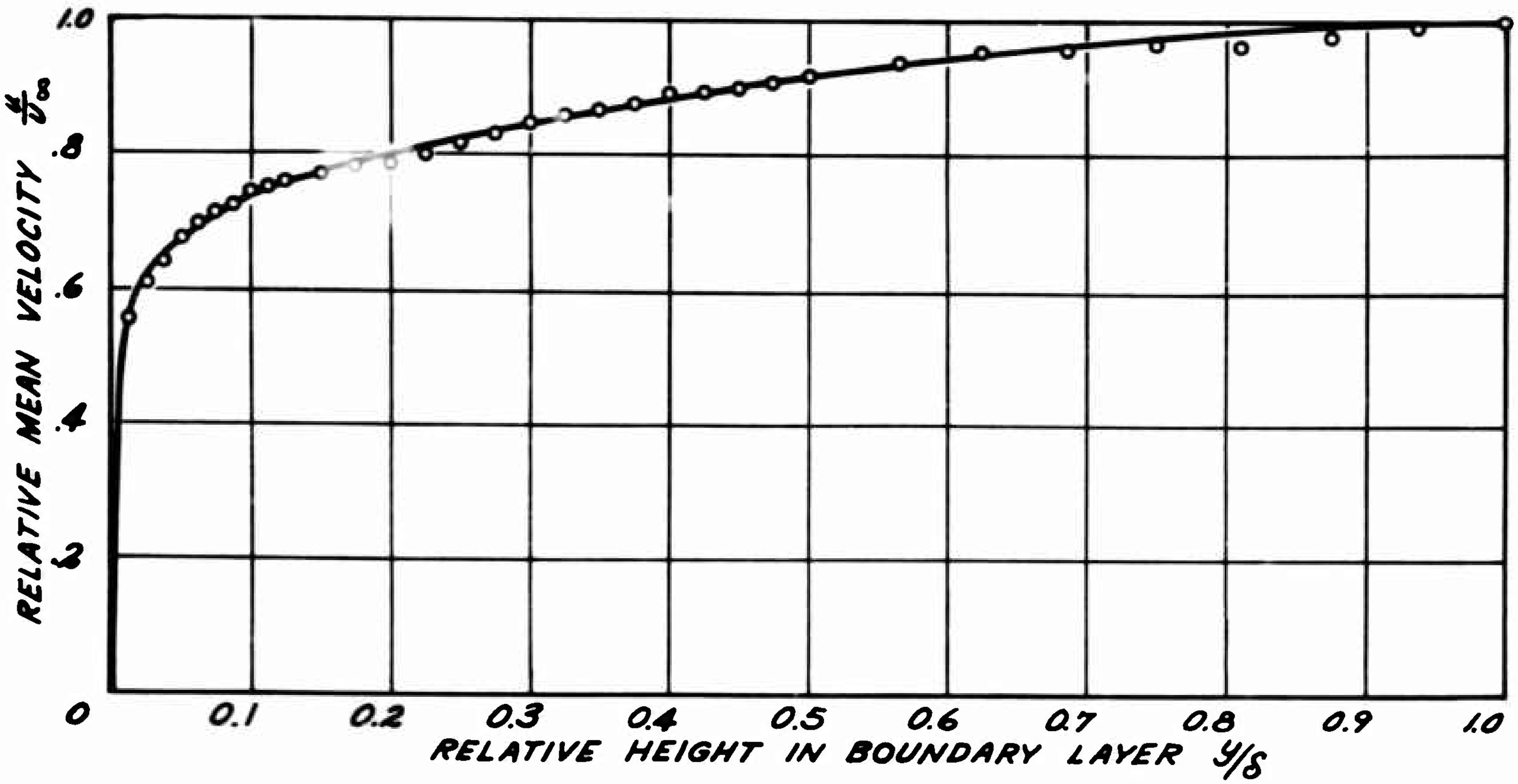


Figure 13. Comparison of Experimental and Theoretical Mean Velocity Profiles in the Turbulent Boundary Layer on a Flat Plate.

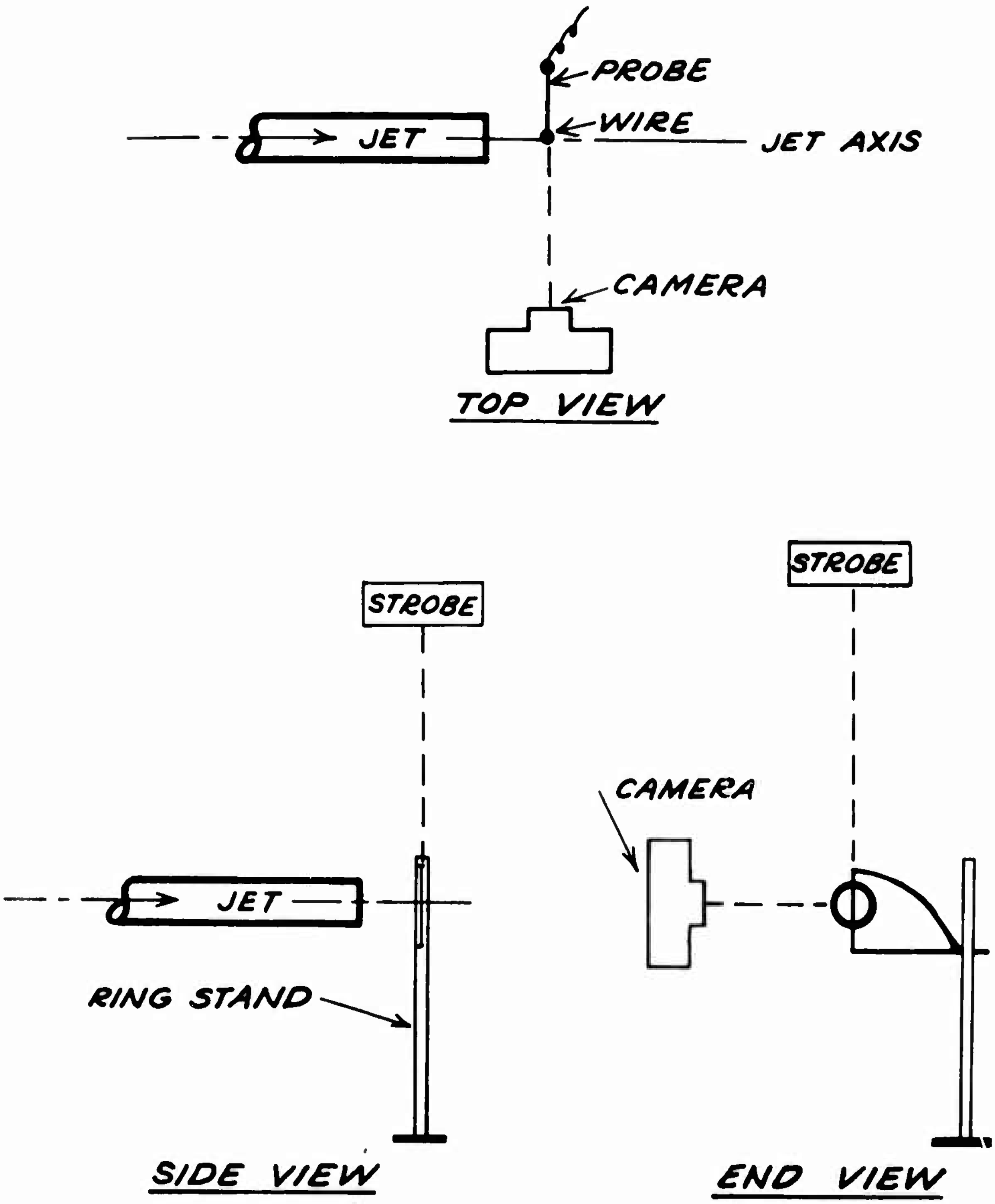
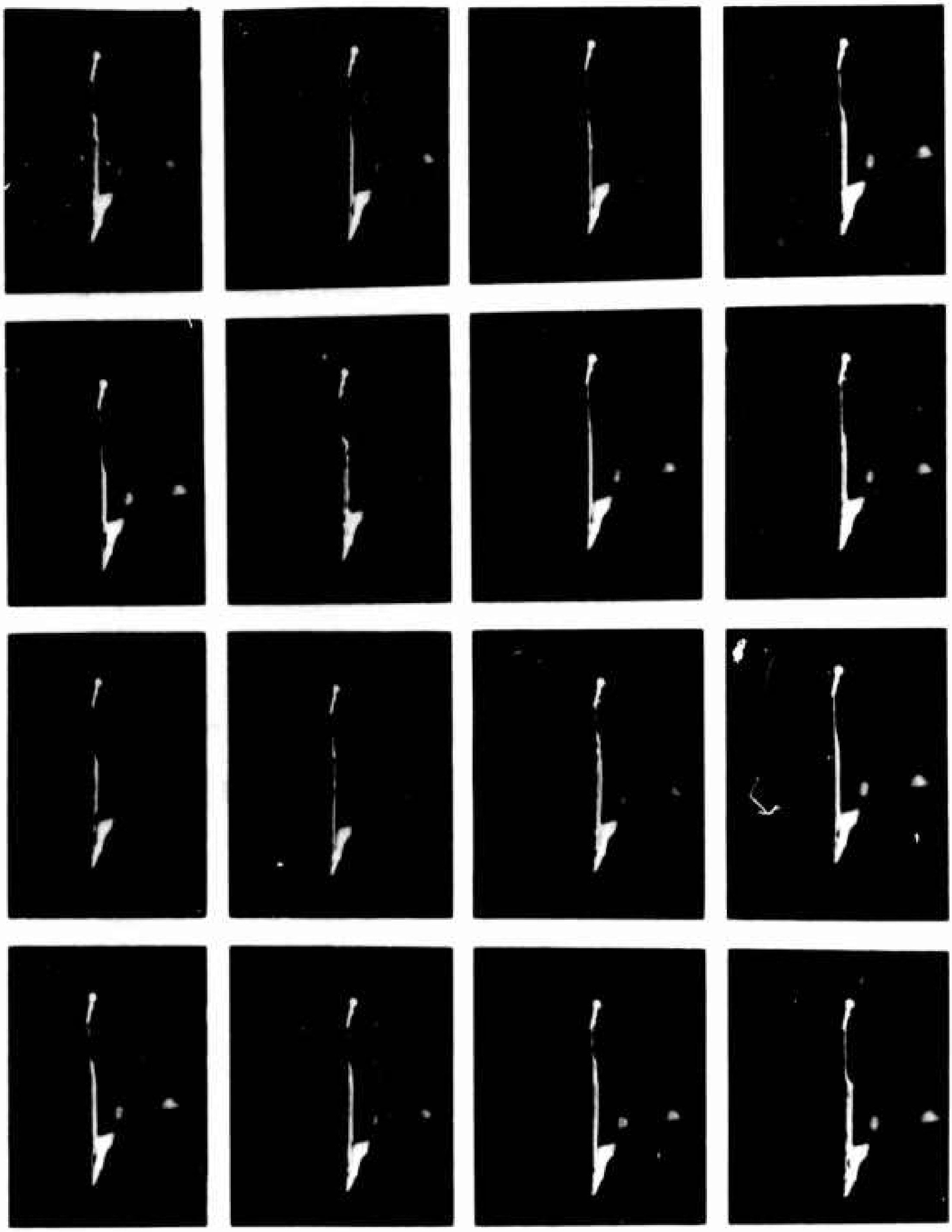


Figure 14. Apparatus Schematic for Turbulent Jet Experiment.

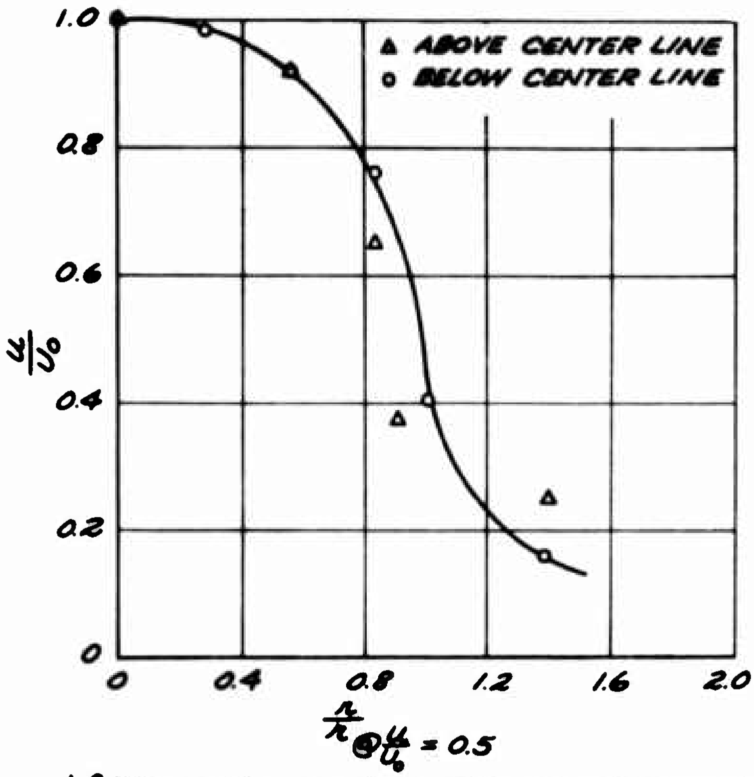


a. 3 Inches from Exit.

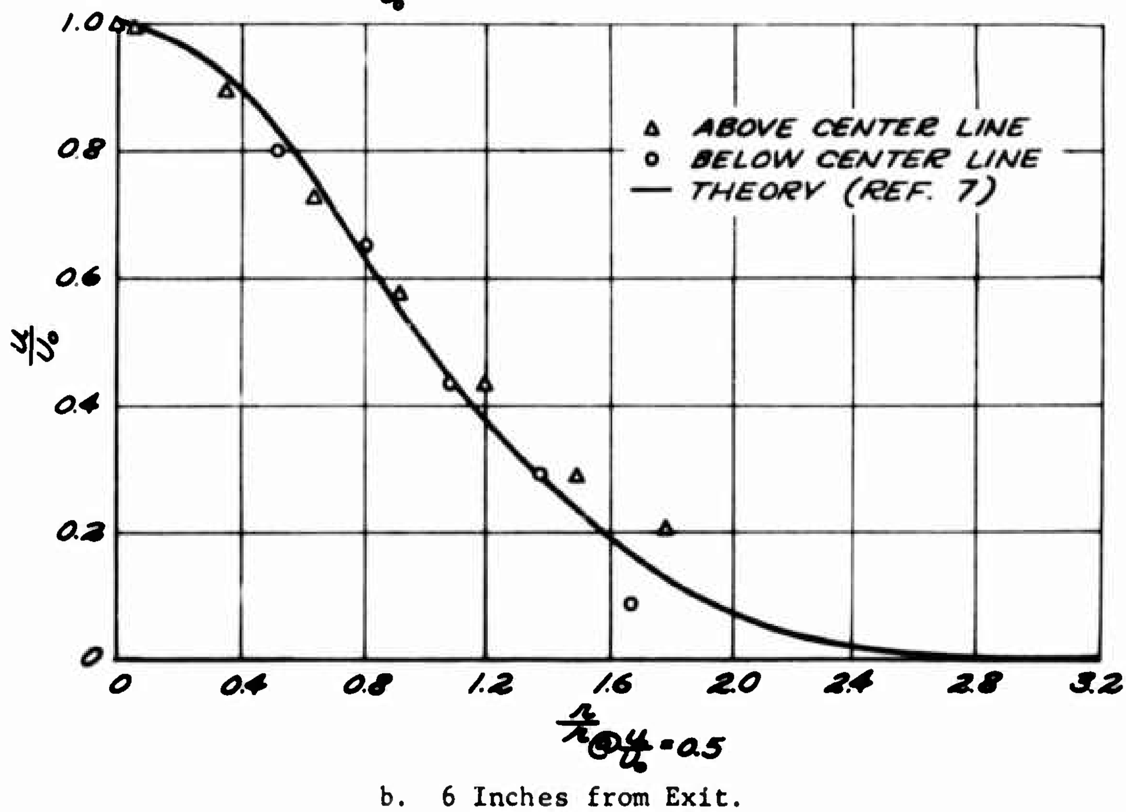
Figure 15. Smoke Profiles in a Turbulent Jet.

b. 6 Inches from Exit.

Figure 15(cont.). Smoke Profiles in a Turbulent Jet.



a. 3 Inches from Exit.



b. 6 Inches from Exit.

Figure 16. Comparison of Experimental and Theoretical Mean Velocity Profiles in a Turbulent Jet.

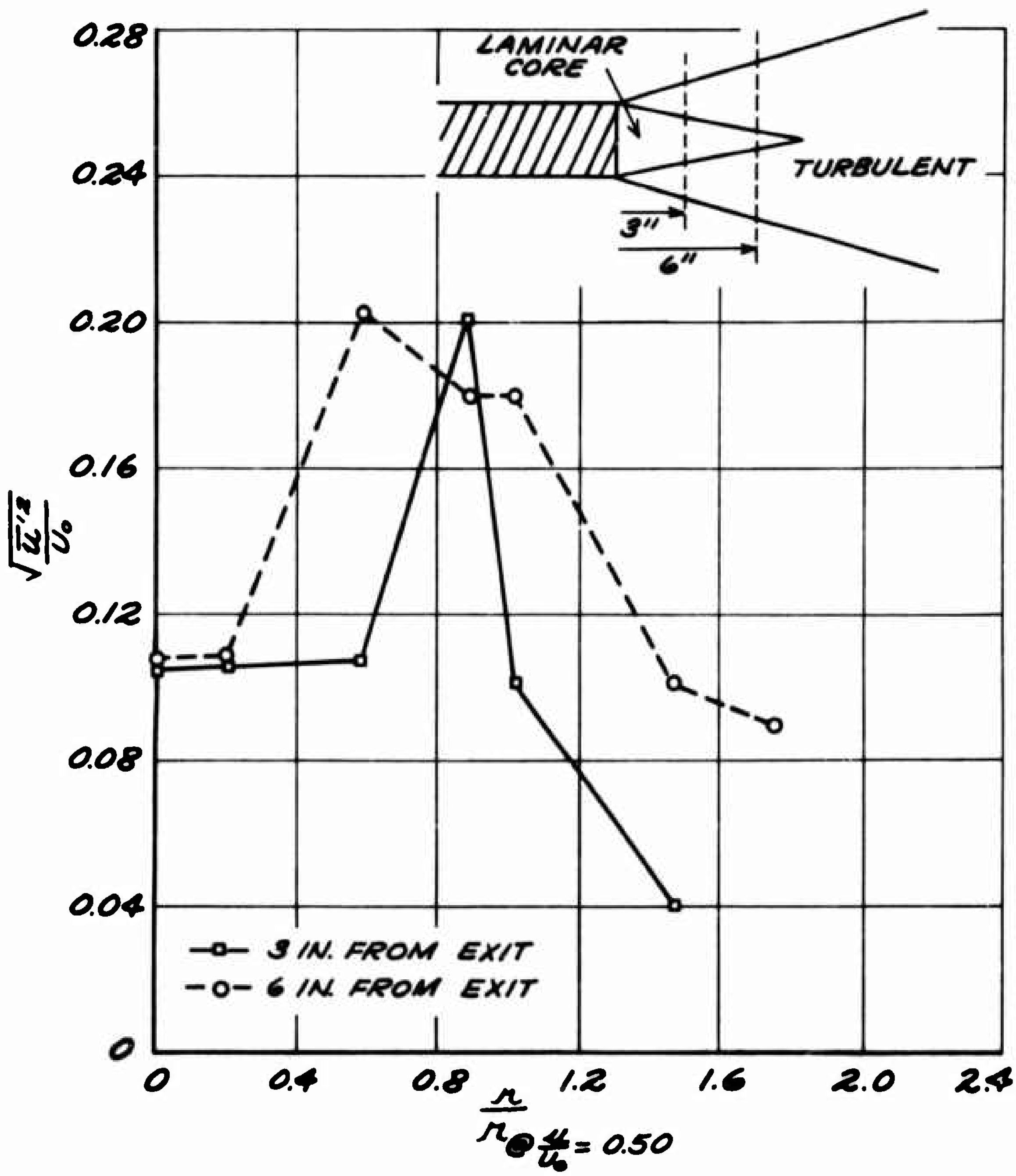


Figure 17. Turbulent Axial Velocity Fluctuations in a Turbulent Jet.

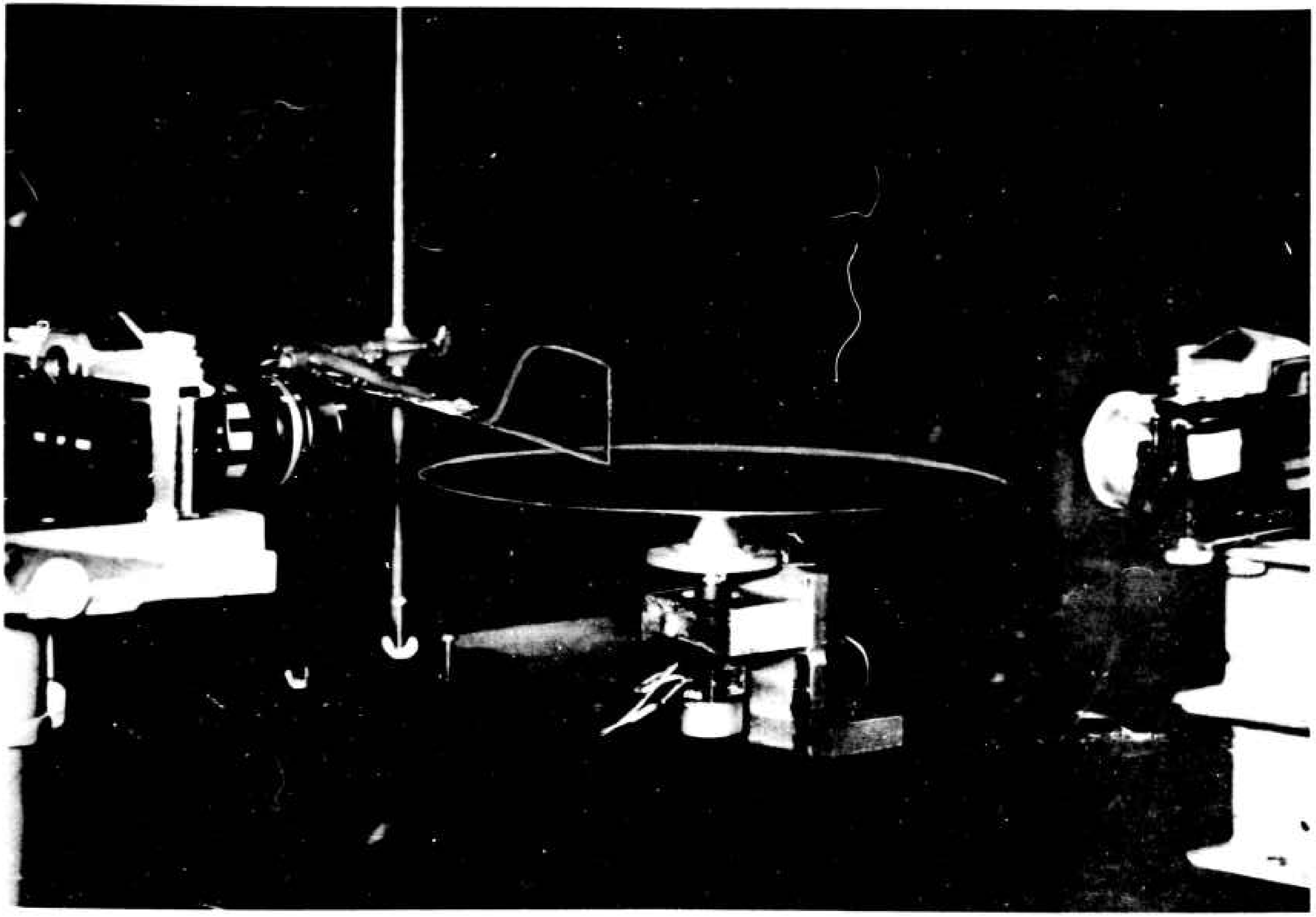


Figure 18. Probe and Camera Arrangement for Velocity Measurement in the Boundary Layer on a Rotating Disk.

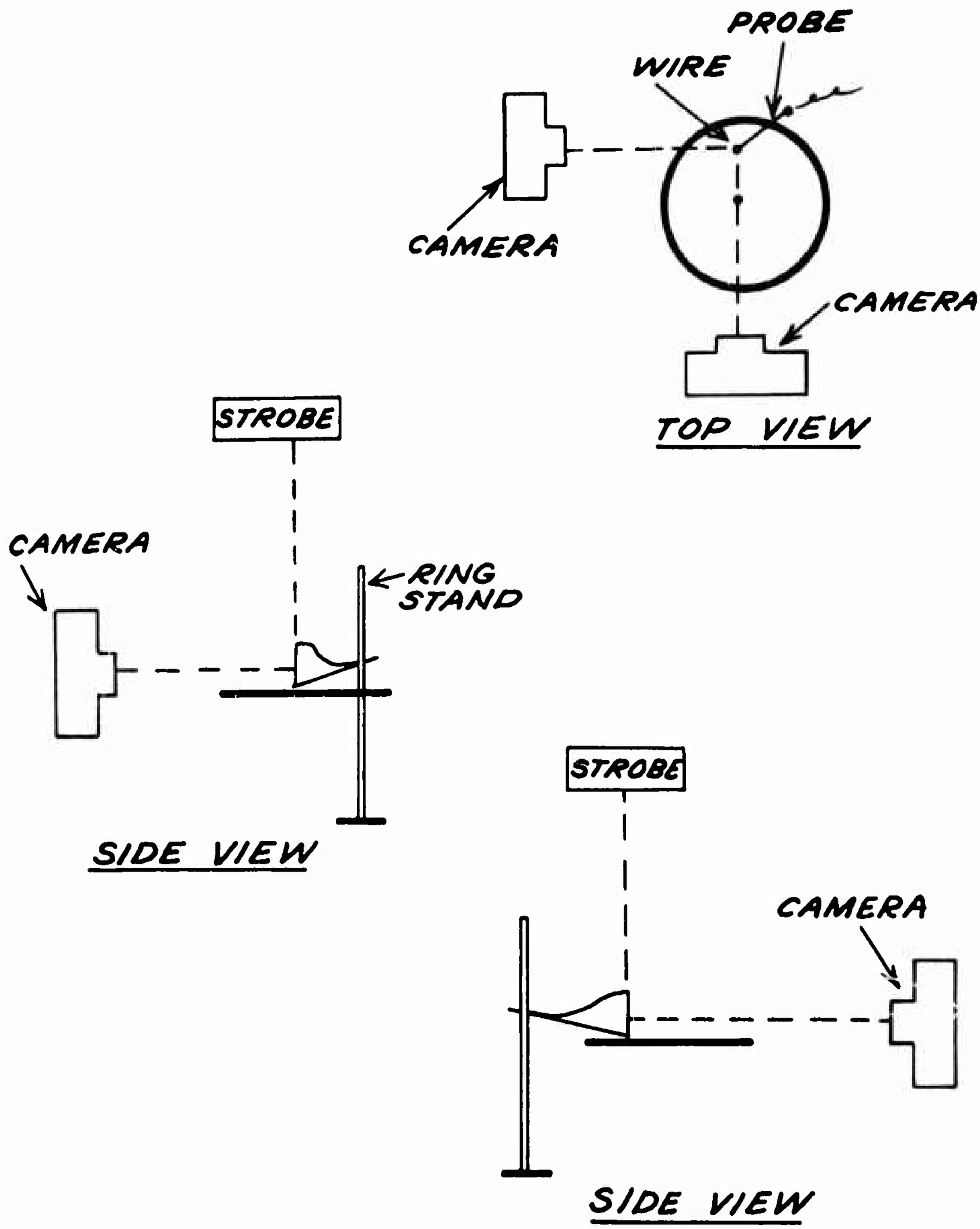
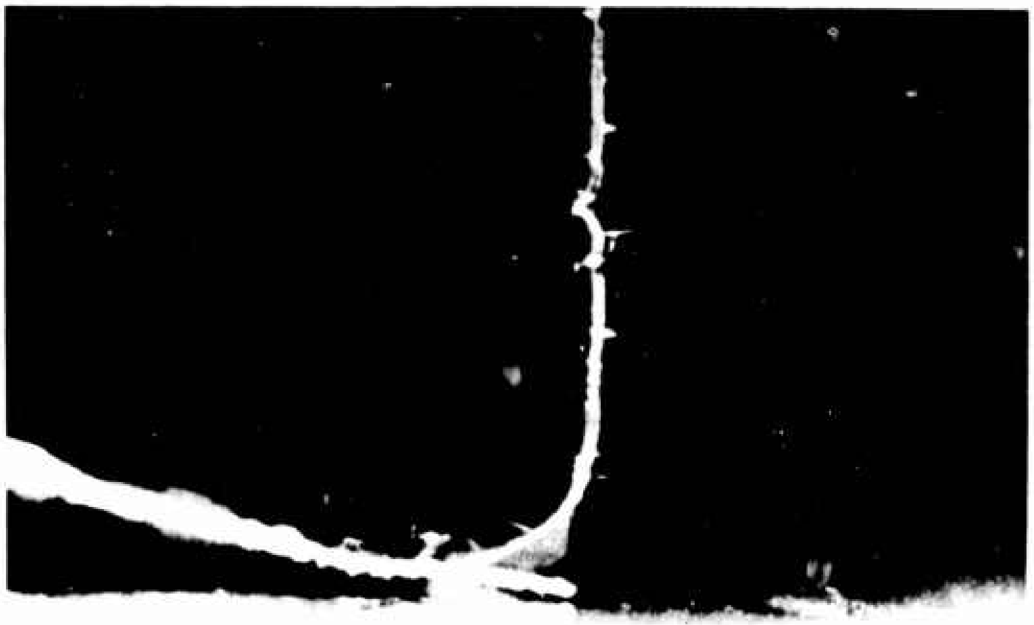
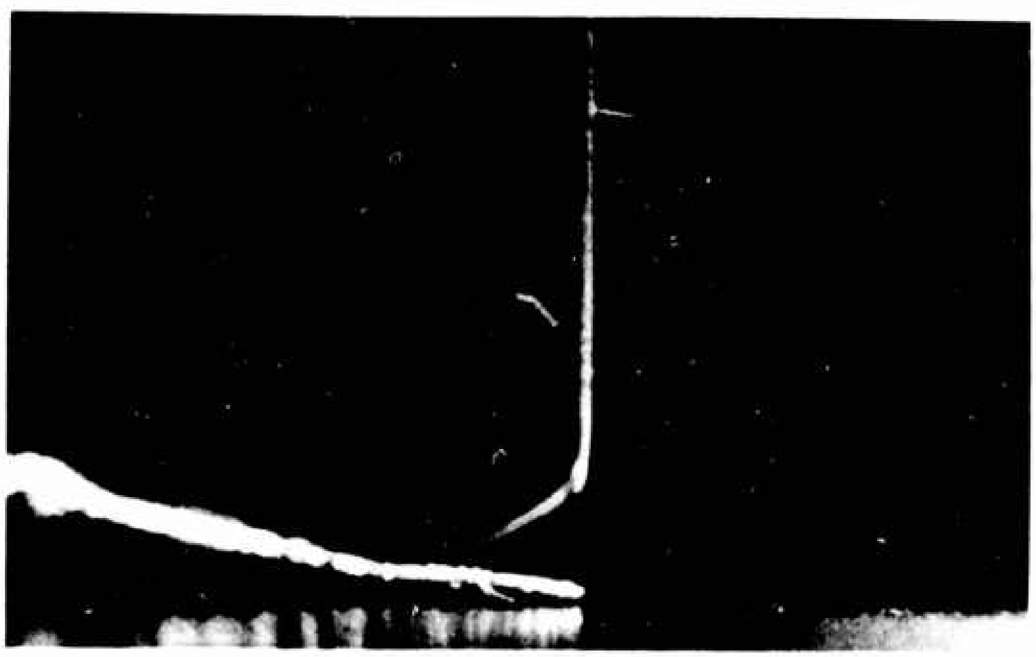


Figure 19. Apparatus Schematic for Rotating Disk Boundary Layer Experiment.

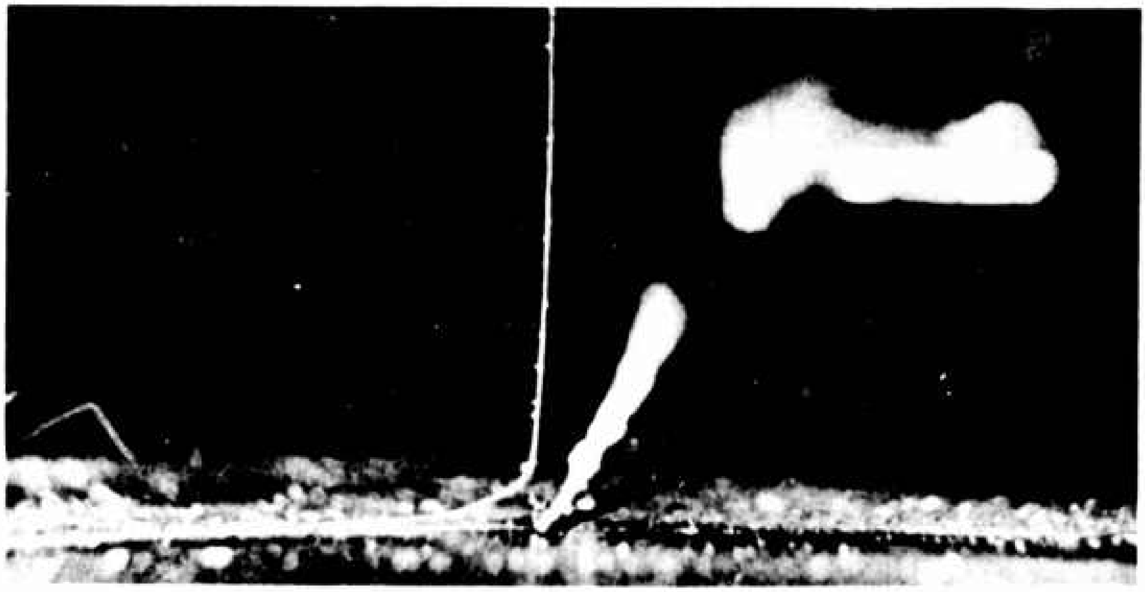


a. 3 Inches from Center.



b. 5 Inches from Center.

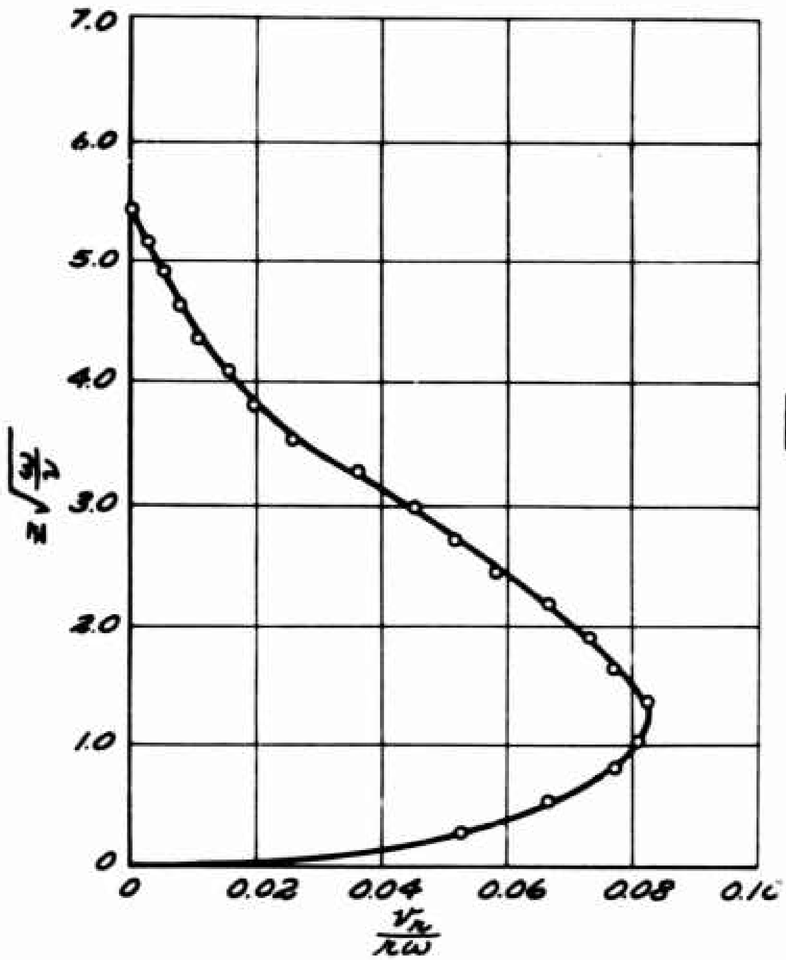
Figure 20. Smoke Profiles of the Laminar Boundary Layer on a Rotating Disk, Radial Direction.



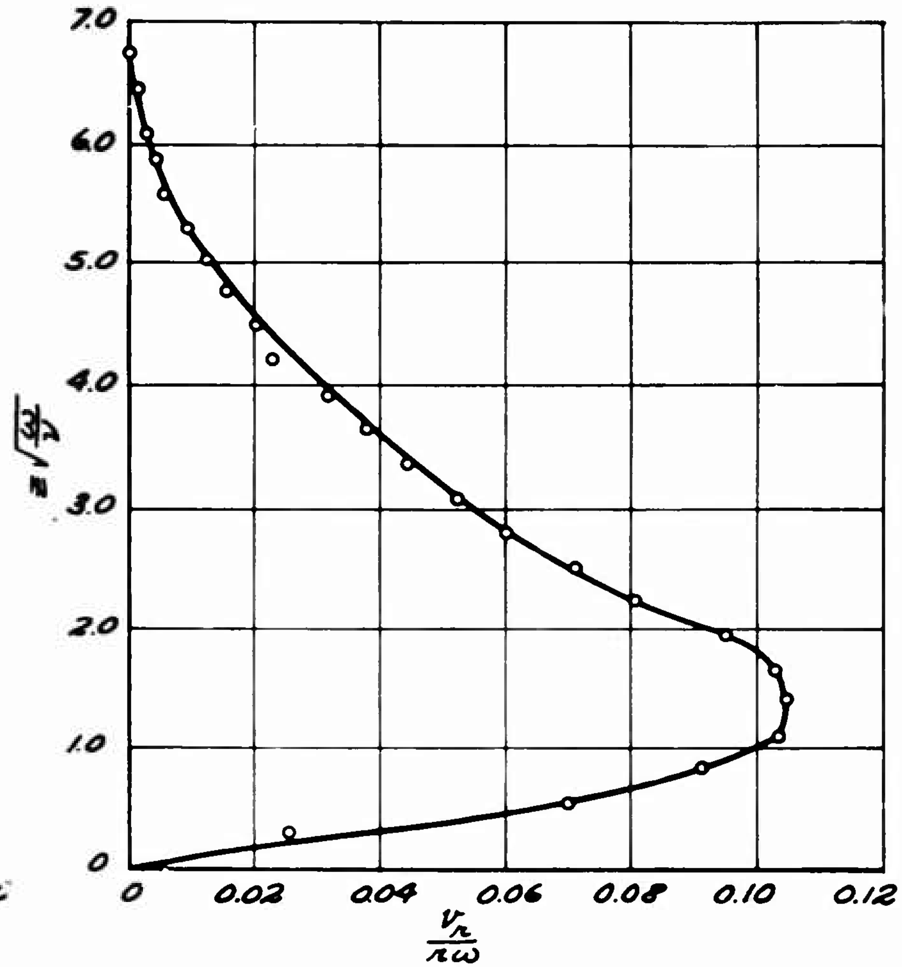
a. 3 Inches from Center.

b. 5 Inches from Center

Figure 21. Smoke Profiles of the Laminar Boundary Layer on a Rotating Disk, Tangential Direction.

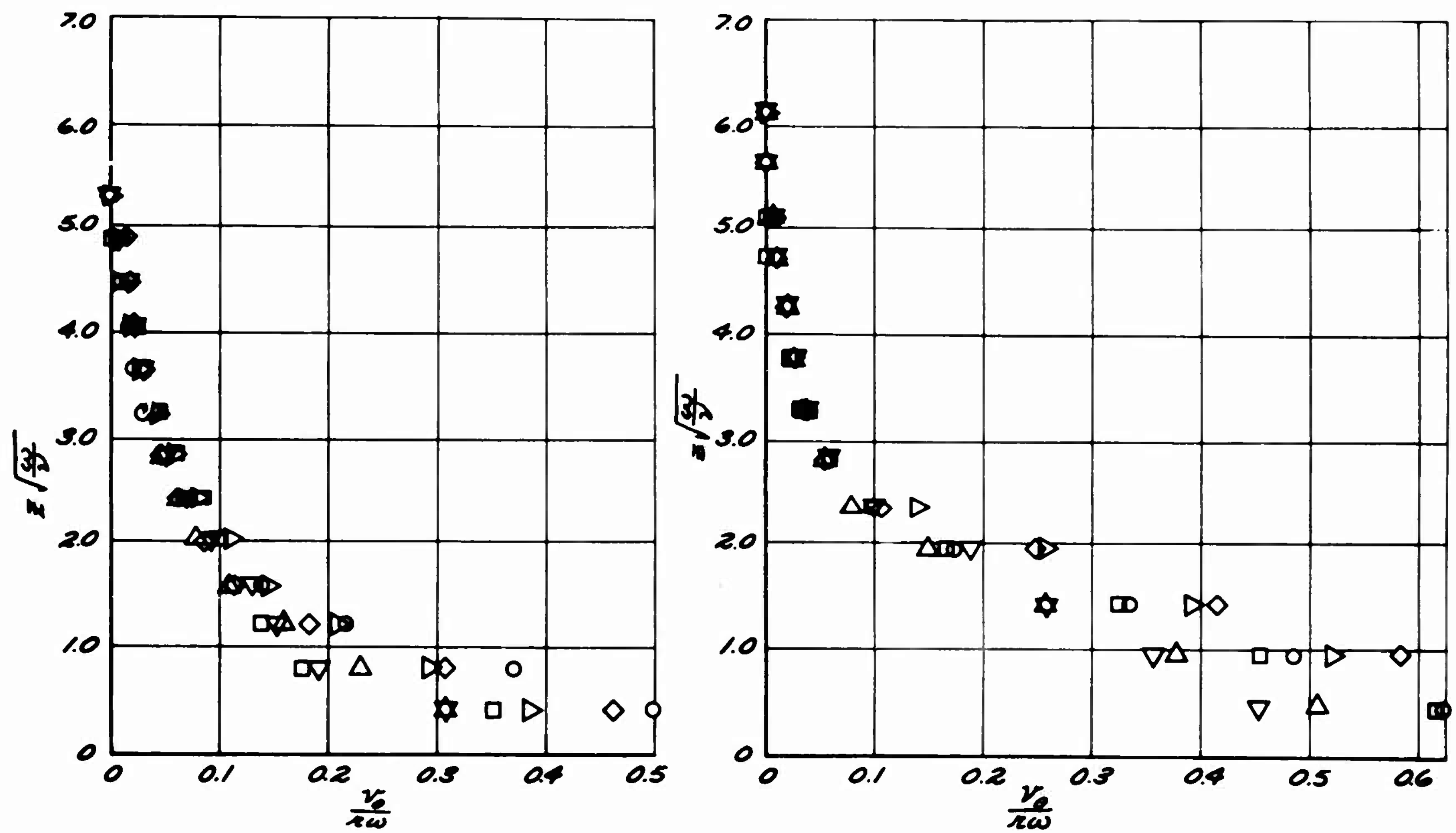


a. 3 Inches from Center.



b. 5 Inches from Center.

Figure 22. Experimental Radial Velocity Profiles in the Laminar Boundary Layer on a Rotating Disk.



a. 3 Inches from Center.

b. 5 Inches from Center.

Figure 23. Experimental Tangential Velocity Profiles in the Laminar Boundary Layer on a Rotating Disk.

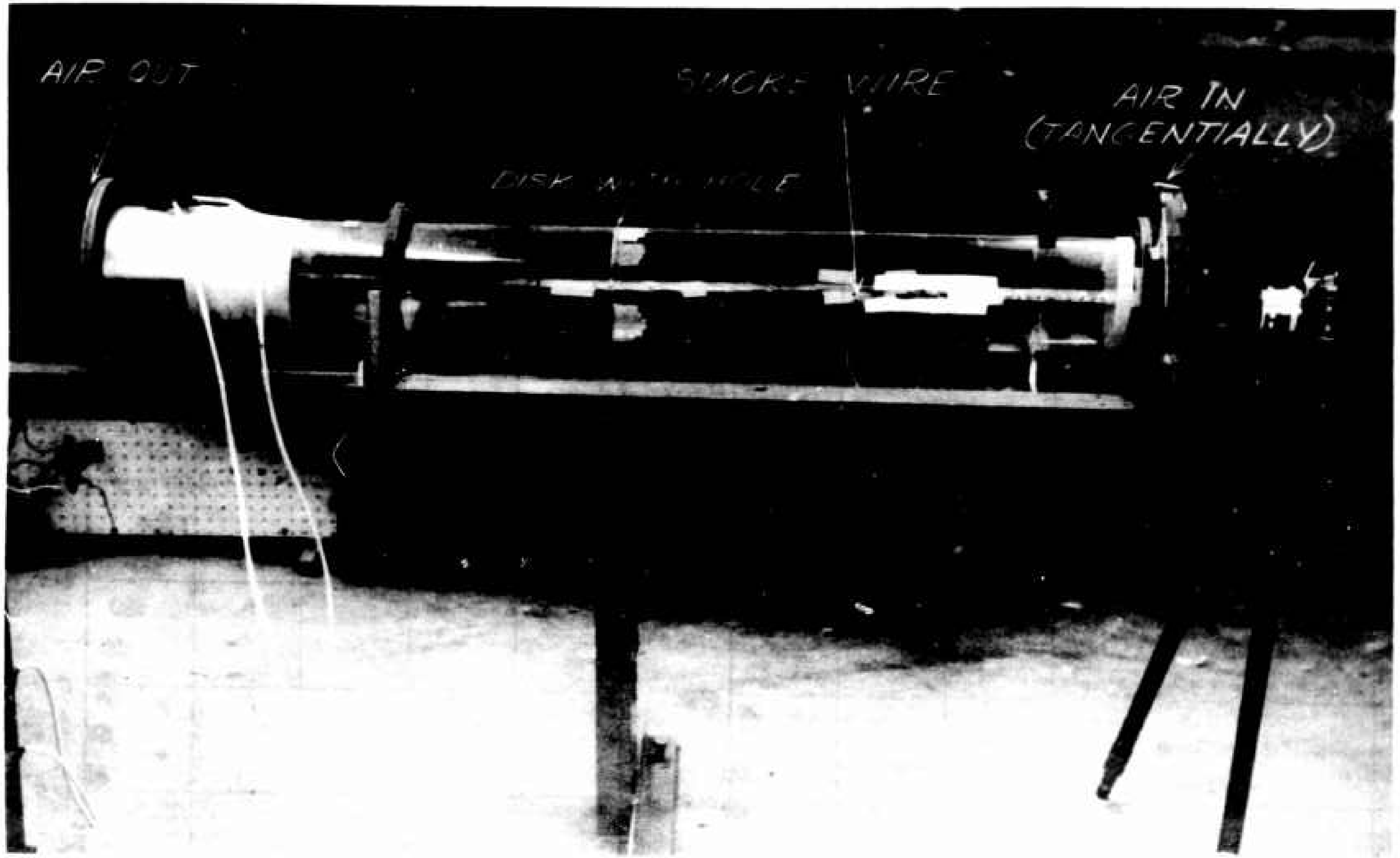


Figure 24. Camera Arrangement for Velocity Measurement of the Tangential Component of a Confined Vortex.

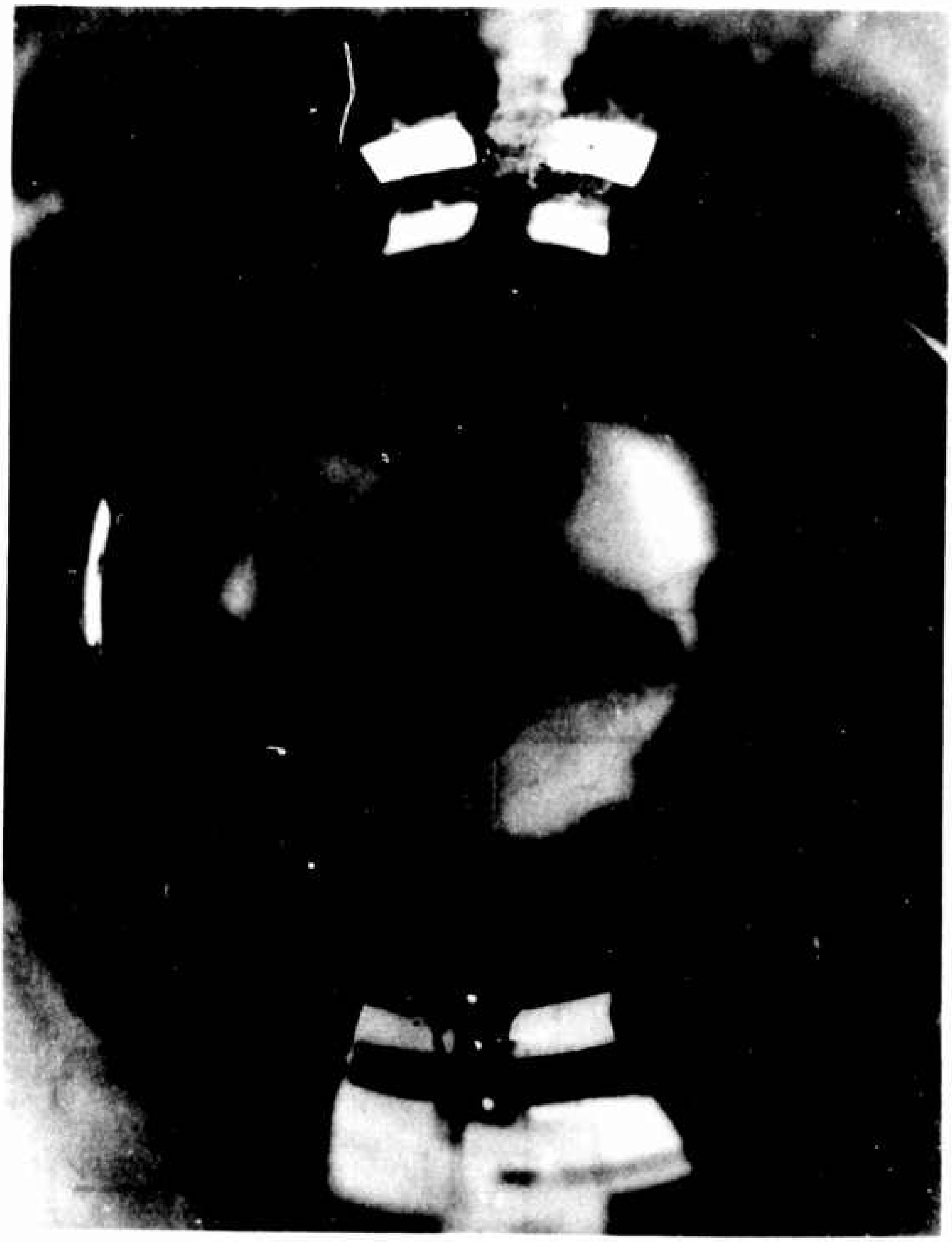


Figure 25. Smoke-Wire Arrangement for Velocity Measurement of the Tangential Component of a Confined Vortex.

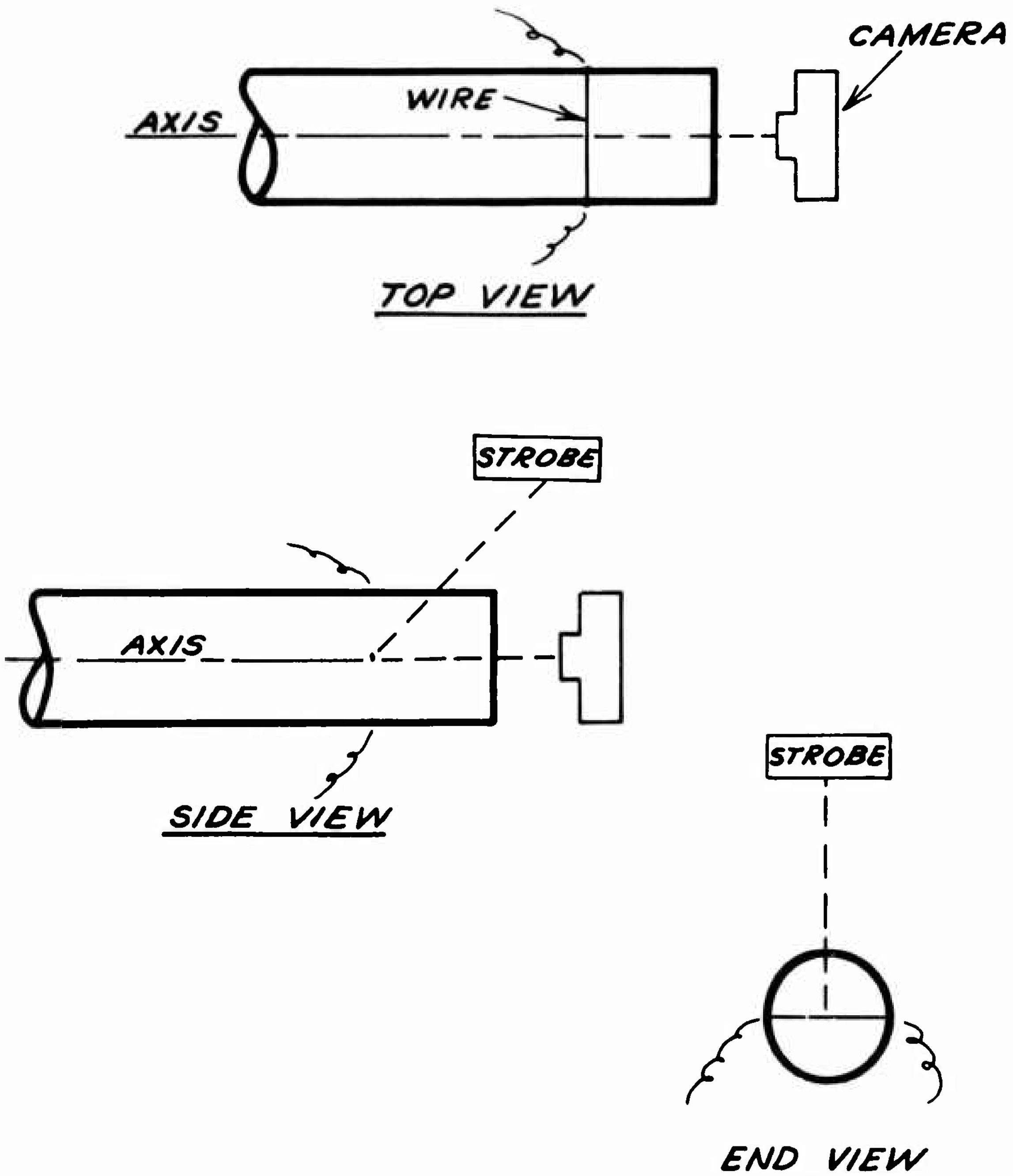
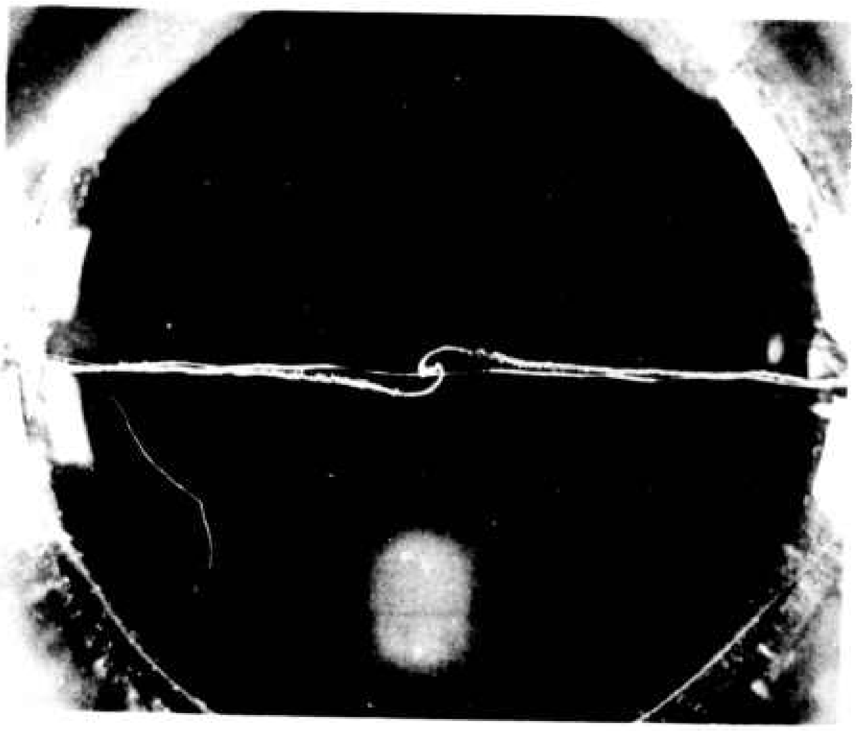
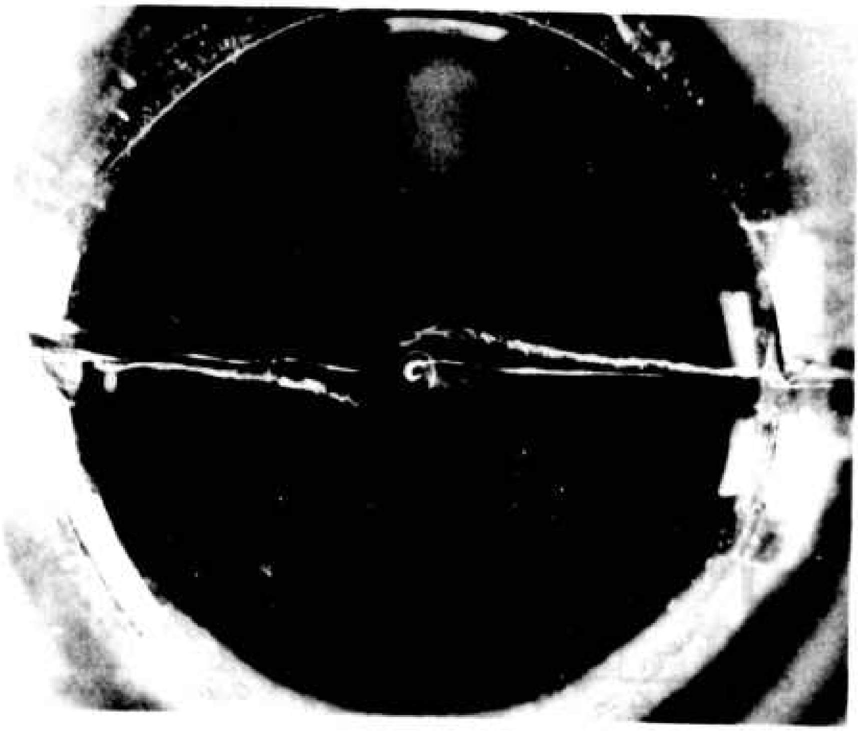


Figure 26. Apparatus Schematic for Confined Vortex Experiment.

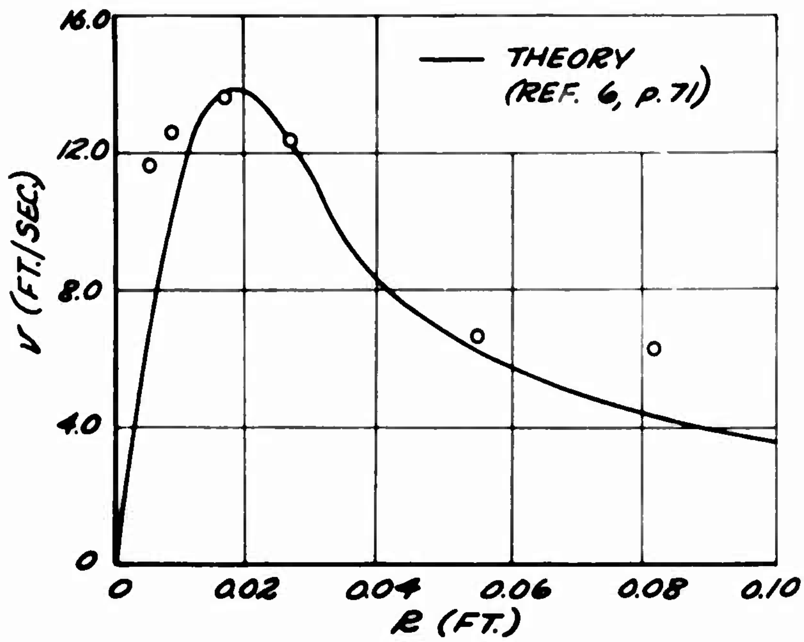


a. Lower Speed.

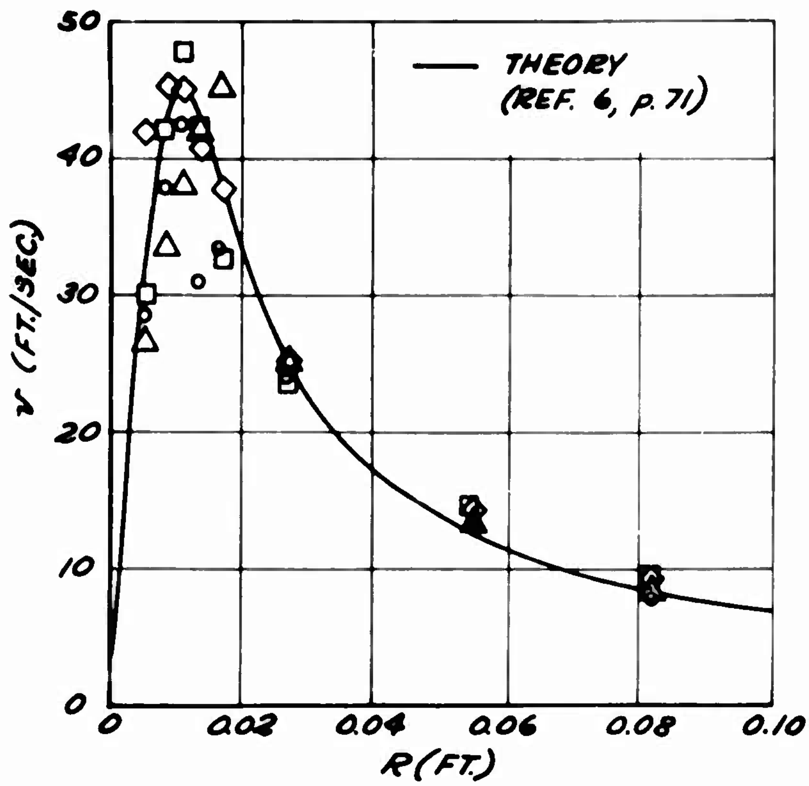


b. Higher Speed.

Figure 27. Smoke Profiles of the Tangential Component of a Confined Vortex.



a. Lower Speed.



b. Higher Speed.

Figure 28. Experimental Tangential Velocity Profiles of a Confined Vortex.

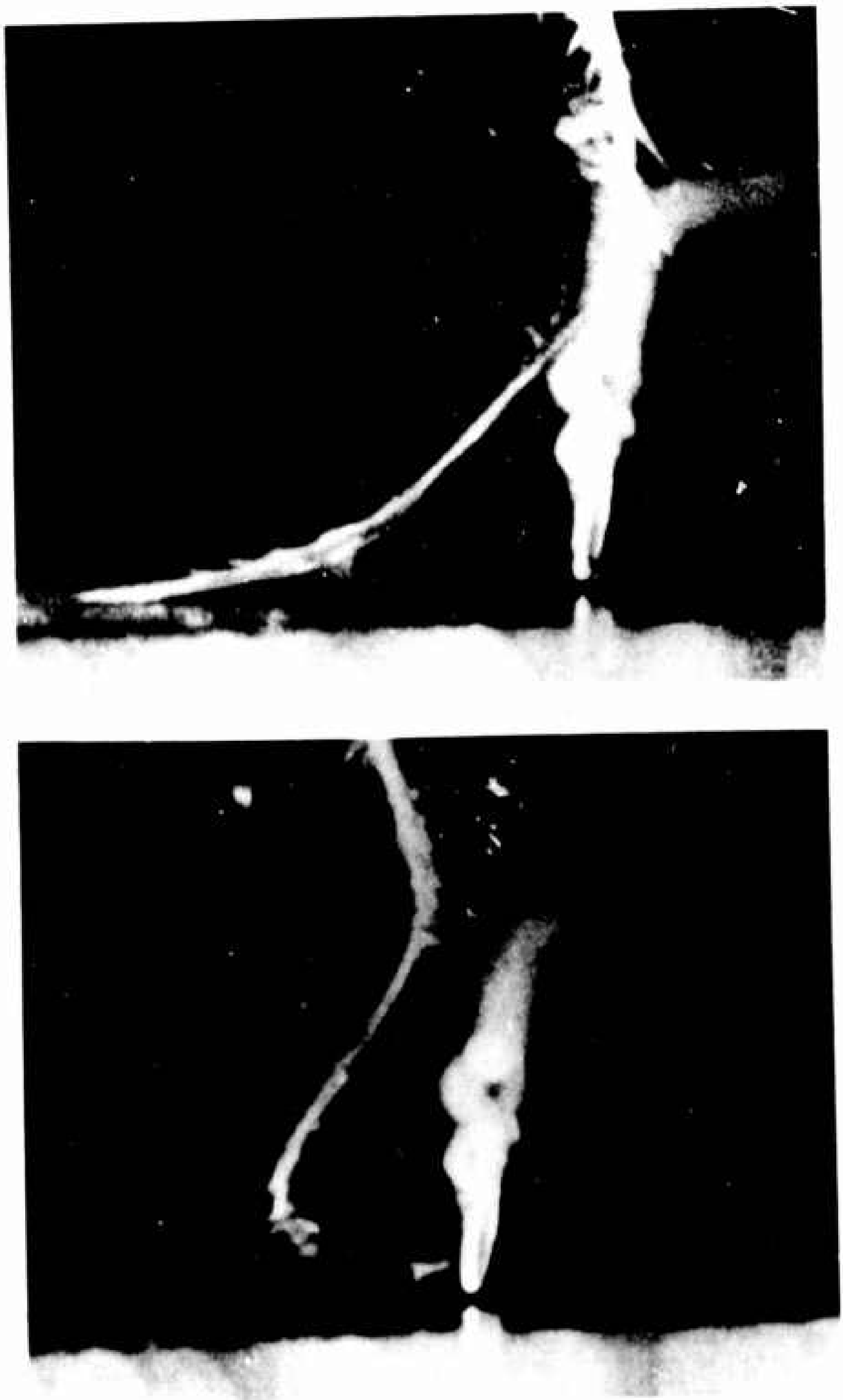


Figure 29. Smoke Profiles of the Laminar Boundary Layer on an Oscillating Flat Plate.

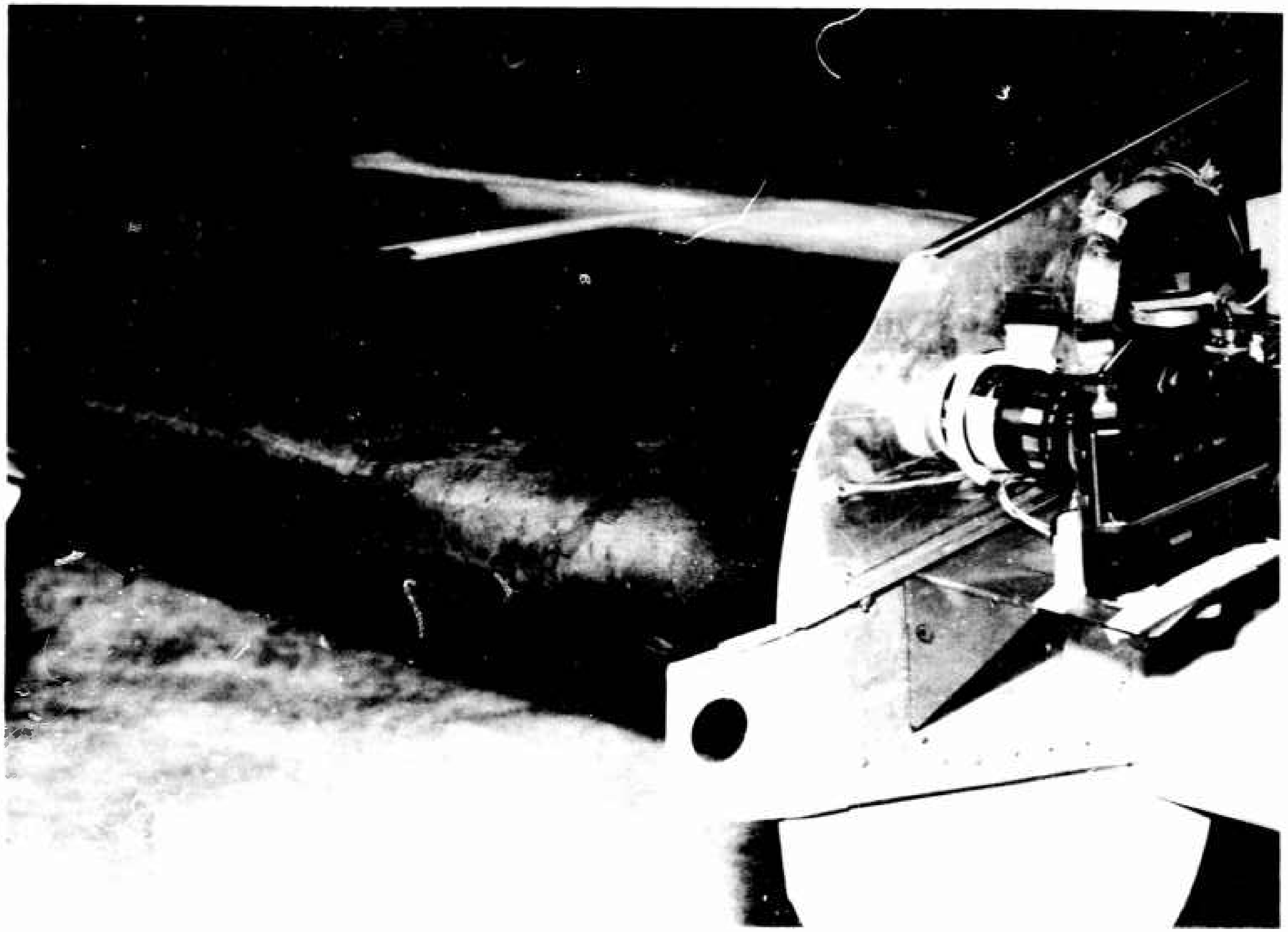


Figure 30. Probe and Camera Arrangement for Velocity Measurement in the Boundary Layer on a Sailplane Wing in Flight.

REFERENCES

1. Bomelburg, H. J., A Method for the Measurement of the Flow of Air by Means of Series of Electronic Sparks, Technical Note OSR-TN-56-38, University of Maryland Institute for Fluid Dynamics and Applied Mathematics, College Park, Maryland, 1955.

2. Cornell, David, Smoke Generation for Flow Visualization, Research Report No. 54, Aerophysics Department, Mississippi State University, State College, Mississippi, 1964.

3. Cornish, Joseph J., III, A Device for the Direct Measurement of Unsteady Air Flows and Some Characteristics of Boundary Layer Transition, Mississippi State University Research Note, TRECOM Technical Report 65-12, U. S. Army Transportation Research Command (now, U. S. Army Aviation Materiel Laboratories), Fort Eustis, Virginia, March 1965.

4. Faris, George Naim, Some Entrainment Properties of a Turbulent Axi-Symmetric Jet, Research Report No. 39, Aerophysics Department, Mississippi State University, State College, Mississippi, 1963.

5. Geller, E. W., "An Electrochemical Method of Visualizing the Boundary Layer", Journal Aeronautical Sciences, Volume 22, No. 12, 1955, pp. 869-870.

6. Schlichting, H., Boundary Layer Theory, 2nd English Edition, McGraw-Hill Book Company, Inc., 1960.

7. Townend, H. C. H., "Hot Wire and Spark Shadowgraphs of the Airflow through an Airscrew", Philosophical Magazine, Volume 7, No. 14, 1932, pp. 700-712.

8. Yamada, Hideo, An Experimental Work on the Unsteady Boundary Layer of an Oscillating Flat Plate, Master's Thesis, Mississippi State University, State College, Mississippi, 1966.

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In the smoke-wire technique, oil is evaporated from a very thin, high-resistance wire by the passage of a large electric current through the wire from a capacitor. The resulting line of smoke is carried downstream with the local velocity of the air, deforming so that a photograph of the smoke line after a measured time delay provides a velocity profile. Since the time delay is very short, this velocity profile is very close to the actual velocity profile at the location of the wire. The technique was evaluated in two- and three-dimensional air flows, both laminar and turbulent, by comparisons with theoretical profiles. Experimental velocity profiles compared quite favorably with theoretical solutions for several different types of flows, including boundary layers, jets, wakes, and vortices. Modifications of the technique and associated apparatus were made in order to extend its scope of application.

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